CLIMATE CHANGE ASSESSMENT

I. BASIC PROJECT INFORMATION

Project Title:	Connecting Economic Clusters for Inclusive Growth in Maharashtra
Project Cost ($ million)**:**	505.00
Location:	Ahmednagar, Hingoli, Jaina, Kolhapur, Nagpur, Nanded, Nashik, Pune, Sangli, Satara districts, Maharashtra, India
Sector:	Transport (Road Transport [Nonurban])
Theme:	
Brief Description:	Maharashtra's strategic roads connecting rural areas and economic centers are congested, unsafe, of poor quality, and exacerbate gender inequity, and social exclusion. This project will support the second phase of the core road network (CRN) development with the proposed roads through the immediate assistance of the Asian Development Bank (ADB) to help address the problem by strengthening the key links in the CRN and improving access to economic opportunities. Under the project, Connecting Economic Clusters for Inclusive Growth in Maharashtra (CECIGM), the Maharashtra Public Works Department (MPWD) will undertake improvements of selected state highways and major district roads. In general, these entail (i) widening of existing roads to two-lane with paved shoulders; (ii) strengthening and reconstruction of roads and drainage structures; and (iii) improvements of road and junction geometries, with the objectives to enhance road transport efficiency and road safety. There are 18 CECIGM project road sections with lengths varying from about nine kilometers (km) to 45 km. Roads, highways, and other road infrastructure (e.g., bridges, culverts, and drains, etc.) increase a community's access to other areas. These in turn increase businesses' labor pool, reduce their costs to obtain input materials and services, and expand their potential market. However, all these potential benefits will not be realized if current and future disaster and climate risks are not factored into the road designs. Climate resilient designs and materials need to be incorporated during the planning stage.

Source: Asian Development Bank.

II. SUMMARY OF CLIMATE CHANGE FINANCE

PROJECT FINANCING		**CLIMATE FINANCE**	
Source	**Amount** ($ million)	**Adaptation** ($ million)	**Mitigation** ($ million)
Asian Development Bank			
Ordinary capital resources (regular loan)	350.00	90.48	4.67
Counterpart			
Government[a]	155.00	22.60	1.17
Total	**505.00**	**113.08**	**5.84**

Source: Asian Development Bank.

III. SUMMARY OF CLIMATE RISK SCREENING AND ASSESSMENT

A. Sensitivity of Project Components to Climate or Weather Conditions and Sea Level	
Project Components	**Sensitivity to Climate or Weather Conditions**
1. Construction of 5 km of realigned interstate roads that avoid flood-prone areas 2. Improvement of selected state highways and major district roads, bridges, and road furniture, and ancillary works 3. Capacity strengthening support for project monitoring and gender equality and social inclusion 4. Implementation of new project monitoring systems and road safety corridors	**High** The state of Maharashtra, with its diverse physiography, climate, and ecosystem variation, is highly prone to climate-related natural risks that include extreme heat, wildfires, droughts, cyclones, floods, landslides, and earthquakes. The project's sensitivity factors to climate or weather conditions includes the following: • Changes in rainfall, temperature, and evaporation patterns can alter the moisture balances in road embankments and pavements. • Rise in air temperature and temperature extremes can accelerate the aging of road surfacing bitumen layers, leading to surface cracking, migration of asphalt and rutting, and increased rate of wear and tear. • Rise in temperature extremes impacts on concrete construction practices, including thermal expansion of bridge expansion joints. • Increase of precipitation and intense precipitation events can cause overloading of drainage systems, causing backups and flooding, and increases in road washouts. • Changes in seasonal precipitation and river flow patterns induce increased risk of floods from runoff, landslides, slope failures, and damage to roads, and bridges. • Storms and more frequent strong cyclones can bring about increased road flooding, greater probability of infrastructure failures, erosion of road base and bridge supports, bridge scour, reduced clearance under bridges, and wind damage to signs, lighting, overhead cables, road signals, and tall structures.

B. Climate Risk Screening[a]	
Risk Topic	**Description of the Risk**
Extreme temperature	**High:** Ten project districts are sensitive to prolonged exposure to high maximum temperatures, ranging from 38°C to as high as 45°C.
Tropical cyclone	**High:** The project districts of Ahmednagar, Nashik, Pune, Sangli, and Satara are classified as *high risk* for tropical cyclone, meaning that there is more than a 20% chance of potentially damaging wind speeds in the project area in the next 10 years.
River floods (associated with extreme rainfall events)	**Medium:** The level of risks posed by river flooding is *medium*, specifically in the districts of Kolhapur and Nanded, which means that there is a chance of more than 20% that potentially damaging and life-threatening river floods occur in the coming 10 years.
Landslides	**Medium:** Kolhapur, Nashik, Pune, and Satara districts are exposed to landslide hazards but are *medium* in terms of levels of risk.

Water scarcity	**Medium:** There is up to a 20% chance that droughts will occur in the coming 10 years.
Earthquake	**Medium:** There is a 10% chance of potentially damaging earthquake shaking in the project area in the next 50 years.
Climate Risk Classification	**High**

C. Climate Risk and Adaptation Assessment

1. Reported climate risks include extreme temperature, tropical cyclone, river floods, landslides, water scarcity, and earthquake.
2. Extreme temperature, which is projected to exceed 40°C on a regular basis, will impact road pavement integrity that cause road surface failure through softening, rutting, and cracking. This will cause bridges to undergo expansion/contraction cycles that impact on bearings and expansion joints, causing its deformation, and failure.

Adaptation Options

1. Climate change adaptation options will address the following climate risks: extreme temperature, tropical cyclones, river floods, landslides, water scarcity, and earthquake.
2. Climate change adaptation may involve additional investments for reconstruction/improvement in bridge protection works and raising of approach to bridge level, river training and protection works, increase in number, and improvement of culvert discharge capacity, improvement in road side drainage structures and capacities, slope stabilization works, bioengineering works on hills, and embankment slopes, raising of embankment height above high flood level, improvement of pavement rigidity in marsh/waterlogged areas, route realignment/construction of new roads, and tree plantation.

D. Climate Risk Screening Tool/Procedure Used

South Asia Department climate risk screening framework and methodology
ThinkHazard assessment tool

C = centigrade, CRVA = climate risk and vulnerability assessment, mm = millimeter, RCP = representative concentration pathway.
[a] ThinkHazard.
Source: Asian Development Bank

IV. CLIMATE ADAPTATION PLANS WITHIN THE PROJECT

No.	Adaptation Activity	Target Climate Risk	Estimated Adaptation Cost ($ million)[a]	Adaptation Finance Justification
1	Reconstruction/improvement in bridge protection works including against scour and raising of approach to bridge level	Flooding arising from extreme precipitation	16.72	Incremental cost to improve bridge design for new, for reconstruction/ repair, and upgraded bridges including raising of approach to new bridge height. Details of computation are in Appendix 1.
2	River training and protection works	Flooding and scouring of riverbanks arising from extreme precipitation	0.30	Protection of banks against increased flow volume and velocity

[a] Conversion: $1.0 = ₹76.32 (25 March 2022).

No.	Adaptation Activity	Target Climate Risk	Estimated Adaptation Cost ($ million)[a]	Adaptation Finance Justification
3	Increase in the number of culverts and general improvement in culvert discharge capacities	Flooding arising from extreme precipitation and surface runoff from rivers	13.99	Includes incremental cost of increased discharge capacities of culverts including new and replaced culverts
4	Improvement in roadside drainage structures and capacities	Flooding arising from extreme rainfall events	13.35	Laying and replacement of longitudinal drains with higher capacities
5	Slope stabilization works	Flooding and extreme precipitation that cause erosion and landslides	21.42	Includes all protection works on hills and embankment slopes except bioengineering works (i.e., retaining walls, gabion, toe walls, anchors works, and gulley protection works)
6	Bioengineering works on hills and embankment slopes	Flooding and extreme precipitation that cause erosion and landslides	1.19	Includes cost of bioengineering works such as turfing to protect slopes and cut hills
7	Raising of embankment height above high flood level in flood-prone sections	Flooding arising from extreme precipitation	29.03	Raising of embankment at minimum 0.6 meters above highest flood level
8	Improvement of pavement rigidity in marsh/waterlogged areas	Extreme heat, flooding, and extreme precipitation	14.47	Includes incremental cost of rigid pavement versus flexible pavement
9	Route realignment/construction of new road	Flooding that disrupts connectivity and causes erosion and landslides	2.50	Full cost of realigned/new road sections that avoid flood-prone areas
10	Preparation of Good Practice Handbook on climate change adaptation and disaster risk reduction in road design and maintenance.	Climate change impacts of road assets	0.10	Cost of remuneration for climate change expert who will prepare the Good Practice Handbook
Total ($ million)			113.08	Total climate adaptation cost does not include project management costs, contingencies, and financing charges as these will be shouldered by the executing agency
Total Civil Works Cost (minus taxes and miscellaneous) ($ million)			346.17	
Climate Change Adaptation Cost as % of Total Civil Works Cost			32.64%	Asian Development Bank will finance 80% of climate adaptation costs

[a] Government of Maharashtra will fund the performance-based maintenance contracts.
Source: Asian Development Bank.

V. CLIMATE MITIGATION PLANS WITHIN THE PROJECT

Mitigation Activity	Estimated GHG Emissions Reduction (tCO_2e/year)[a]	Estimated Mitigation Costs ($ million)	Mitigation Finance Justification
In-situ soil stabilization method	Not derived	1.45	Reduction of need for transport and actual volume of raw materials for embankment
Recycling of asphalt	Not derived	3.53	Reduction of raw materials requirement
Tree plantation	354[b]	0.86	Carbon sequestration capacity of mature trees from additional tree plantation activity
Total	354	5.84	

GHG = greenhouse gas, tCO_2e = tons of carbon dioxide equivalent.

[a] Energy savings/year x emission factor = GHG emissions reduction.

[b] GHG emissions reduction reflected here is only for the additional tree plantation activity. GHG emissions reduction reflected in PAG is from TEEMP modeling. Emissions reduction is computed as Total number of trees felled x Additional plantation ratio x Survival rate x Carbon sequestration ability of mature trees based on generally accepted estimate of 22 kg/year of CO_2 per mature tree per year.

Source: Asian Development Bank.

DETAILS OF CLIMATE ADAPTATION MEASURES

CECIGM			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total	
			EPC 10	**EPC 11**	**EPC 12**	**EPC 13**	**EPC 14**	**EPC 15**	**EPC 16**	**EPC 17**	**EPC 18**	**EPC 19**	**EPC 20**	**EPC 21**	**EPC 22**	**EPC 23**	**EPC 24**	**EPC 25**	**EPC 26**		
No.	**Items**	**Works**	**Costs in INR Million**																	INR Million	USD Million
A	Bridges	Reconstruction/Improvements of Major Bridges	0	18.039	0	0	0	0	25.710	446.52	44.81	0	0	0	0	0	0	0.000	0	535.08	7.01
		Reconstruction/Improvements of Minor Bridges	0	33.480	18.936	52.000	47.630	0	41.040	11.78	107.15	106.08	148.42	0	54.205	17.635	18.801	44.210	39.650	741.02	9.71
B	River Training and Protection	River Training and Protection Works	0	0	0	0	0	0	0	0	0	0	0	0	22.710	0	0	0	0	22.71	0.30
C	Culverts	Improvement of Culverts Including Additional New	45.301	22.61	108.623	70.900	80.143	66.88	70.775	40.879	52.55	115.74	57.44	0	67.863	44.461	52.074	99.780	72.000	1,068.02	13.99
D	Drainages	Overall Improvement of Road Side Drains	31.490	24.230	145.088	29.810	103.855	19.173	17.836	109.527	67.31	29.47	72.07	20.87	4.606	133.395	136.752	65.468	7.890	1,018.84	13.35
E	Slope Stabilization	Slope Stabilization Works	85.380	39.340	261.853	1.500	8.900	6.25	108.022	146.739	138.4	25.23	284.32	5.79	82.312	156.945	217.000	24.840	42.210	1,635.06	21.42
F	Bioengineered Slope	Bioengineering Works on Hills/Embankment Slopes	91.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91.01	1.19
G	Road Embankment	Improvement of Road Embankments above HFL	0.000	149.810	0	73.000	52.660	93.56	0	78.710	319.39	542.37	516.94	29.84	193.110	0.000	0	125.240	41.310	2,215.94	29.03
H	Pavement	Rigid Pavement in Marshy/Waterlogged Areas	0	13.749	22.915	0	0	13.444	73.329	175.685	196.156	146.353	116.410	6.111	39.628	200.311	100.553	0.0	0.0	1,104.64	14.47
I	Relocation/Realignment	New Road/Realignment	0	0	0	0	0	0	0	61.102	129.456	0	0	0	0	0	0	0		190.56	2.50
Total Above, INR Million			253.181	301.254	557.415	227.210	293.188	199.307	336.712	1,070.941	1,055.251	965.243	1,195.600	62.611	464.433	552.747	525.180	359.538	203.060	8,622.87	112.98
Total Civil Works Cost (minus taxes and miscellaneous), INR Million			1,233.30	1,142.00	1,882.30	966.10	1,317.50	824.80	1,639.60	2,551.67	1,889.54	1,908.79	2,331.42	784.45	2,031.83	1,775.60	1,954.90	1,513.90	671.60	26,419.30	
Climate Change Adaptation Cost as % of Total Civil Works Cost			20.5%	26.4%	29.6%	23.5%	22.3%	24.2%	20.5%	42.0%	55.8%	50.6%	51.3%	8.0%	22.9%	31.1%	26.9%	23.7%	30.2%	32.6%	

EPC = engineering, procurement, and construction, HFL = highest flood level, INR = Indian rupee, USD = United States dollar.
Source: Asian Development Bank.

Climate Risk and Adaptation Assessment

August 2022

India: Connecting Economic Clusters for Inclusive Growth in Maharashtra

Prepared by the Public Works Department, Government of Maharashtra for the Asian Development Bank.

ABBREVIATIONS

ADB	–	Asian Development Bank
CCKP	–	Climate Change Knowledge Portal
CECIGM	–	Connecting Economic Clusters for Inclusive Growth in Maharashtra
CRA	–	climate risks assessment
EPC	–	engineering, procurement, and construction
HFL	–	high flood level
IEE	–	initial environmental examination
IMD	–	Indian Meteorological Department
INR	–	Indian rupee
IPCC	–	Intergovernmental Panel on Climate Change
JJAS	–	June, July, August, September
MDR	–	major district road
MPWD	–	Maharashtra Public Works Department
MSAPCC	–	Maharashtra State Action Plan on Climate Change
NH	–	national highway
SH	–	state highway
SSP	–	shared socioeconomic pathway

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I. INTRODUCTION

A. Background

1. Maharashtra is the second largest state in India with a total land mass area of around 307,713 square kilometers. From an administrative perspective, the state is divided into six divisions that are further divided into 36 districts. The state is spread over a wide geographical area and exhibits diverse climatic regions owing to its varied physiography and seasonal rainfall patterns. The Köppen-Geiger climate classification is one of the most widely used climate classification systems that divides the world's climates into five main climate groups: *A* (tropical), *B* (dry), *C* (temperate), *D* (continental), and *E* (polar), with each group divided into several subgroups based on seasonal precipitation and temperature patterns. The state of Maharashtra has both tropical and dry climates[1] with subgroups: (i) *BSh* – hot semi-arid climate, in the districts of Amravati, Aurangabad, Pune, Sangli, and Solapur; (ii) *Aw* – tropical savanna climate, in the districts of Kolhapur, Mumbai, Nagpur, Nashik, and Vasai-Virar; (iii) *Am* – tropical monsoon climate, in the districts of Bhiwandi, Kalyan-Dombivili, Lonavala, Ratnagiri, and Ulhasnagar; (iv) *Csa* – hot summer Mediterranean climate, in the districts of Bhawade, Chikhaldara, and Toranmal.

2. Road transport is vital to economic development, trade, and social integration. Road networks and systems in Maharashtra are managed by a myriad of organizations. The national highways (NH) running through the state are managed by the central government, the state highways (SH) and major district roads (MDR) by the Maharashtra Public Works Department, urban roads by the respective municipal entities, and rural roads by local governments called *zilla parishads/panchayats*, and so on.

3. The road network in Maharashtra totals about 303,357 kilometers (km), including national highways with a total length of 12,275 km that connect six neighboring states. State highways together with major district roads are arterial routes within the state, linking district headquarters, and important towns and linking them with national highways and state highways of neighboring states. The road density in Maharashtra is said to be above India's national average. The state has the largest share of state highways and major district roads in the country with a total length of 87,087 km as of 2018 (Table 1). State highways and major district roads are administered and financed by the state government.

Table 1: **Maharashtra Road Networks as of 2018**

	National Highways	Major State Highways	State Highways	Major District Roads	Other District Roads	Rural Roads	Total
Length (kilometer)	12,275	3,862	30,588	52,637	58,116	145,879	303,357
Distribution (%)	4	1	10	17	19	48	100

Source: Maharashtra Public Works Department.

4. The Government of Maharashtra has applied for a loan from Asian Development Bank (ADB) toward the cost of the Maharashtra State Roads Improvement Project (MSRIP) with the primary objective of improvement of state highways and major district roads under engineering, procurement, and construction (EPC) contracts. The Maharashtra Public Works Department (MPWD) is the executing agency of the project.

5. Under the proposed second loan in the project Connecting Economic Clusters for Inclusive Growth in Maharashtra (CECIGM), the MPWD will undertake improvements of selected SHs and

[1] Climate-Data.org. *Climate: Maharashtra*.

MDRs. The improvements will include widening of existing roads to two-lane with paved shoulders, strengthening, and reconstruction of roads and drainage structures, improvement of roads, and junction geometries, with the objective to enhance road transport efficiency and road safety. Table 2 lists 14 CECIGM subproject roads of lengths varying from about 9 km to 45 km.

Table 2: CECIGM Project Roads

No.	Package No.	Connectivity/Activity (Improvement/Reconstruction/Widening)	Length (km)	District Location
1	EPC 10	SH 68 Road from Siddhatek (Pune district border) to Korti (Solapur district border)–Section of SH 68 from km 103/650 to 127/200 and km 0/000 to km 0/430 near Siddhatek temple (Length 23.98 km)	23.98	Ahmednagar
2	EPC 11	MDR-84 Road from NH-9 (Pune–Solapur) to Khadki–Paravadi – Shetphalgade–Lakadi–Nimbodi–Bhawani Nagar–Sansar Kurwali– from km 00/000 to 21/900 (Length 21.90 km)	21.90	Pune
3	EPC 12	Yavat Malshiras Saswad Kapurhol Bhor Mandhardev Wai Surur Road–Section of SH 119 km 76/0 to 126/500 (Section 76/0 to 117/100 and 0/0 to 4/257)	45.357	Satara and Pune
4	EPC 13	SH 117 to Adarki Mirgaon Phaltan Road SH 149 km 0/0 to 26/400 (Part I km 0/000 to 21/000)	21.000	Satara
5	EPC 14	SH 191 Road from NH 204 to Kerli Kotoli Nandgaon Nanadari Road SH 191 from km 0/000 to 24/000 (Length 24 km)	24.000	Kohlapur
6	EPC 15	(1) Karanja–Bharsingi–Jalalkheda–Mowad to district border District Nagpur (km 51+600 TO km 62+100), 10.5 km (2) Kalmeshwar–Ghorad–Mohpa–Telgaon Road SH 349 (km 0+000 to km 9+250)	10.50	Nagpur
7	EPC 16	Balapur to Kandil Bothi Rameshwar Tanda Wadgaon Girgaon up to NH-161 MDR-10 km 00/00 to 36/020 (Section 0/00 to 28/672)	28.672	Hingoli
8	EPC 17	Nila Junction–Brahmanwada Amdura Malkautha Balegaon Karegaon Phata–Babli Phata Bellur to Naigaon to state border MDR-83 (1) Part of Nila junction to Mugat junction km 0/00 to 14/815 (2) Chaitanya Nagar Shiv Mandir to Asna Bridge Junction km 0/00 to 3/515 (3) Brahmanwada Road km 0/00 to 1/590 (1.59 km)	19.920	Nanded
9	EPC 18	Nila Junction–Brahmanwada–Amdura–Malkautha–Balegaon–Karegaon–Phata Babli–Phata Bellur to Naigaon to state border MDR 83 in Nanded District (1) Part of Mugat junction to Khujda junction km 14/815 to 34/750 (2) Aamdura km 0/00 to 3/330 (3) Aamdura link road km 0/00 to 0/595 (4) Malkautha km 0/00 to 1/975	25.835	Nanded
10	EPC 19	Nila Junction–Brahmanwada–Amdura–Malkautha–Balegaon–Karegaon Phata–Babli Phata Bellur to Naigaon to state border MDR 83 in Nanded District (1) Part of Khujda Junction to Karegaon Phata km 34/750 to 60/400 (Total length 25.650)	25.650	Nanded
11	EPC 20	Nila Junction–Brahmanwada–Amdura–Malkota–Karegaon–Bhabli Phata–Bellur Phata–Nayagaon state border MDR 83: (1) Part of Khujda Junction to state border km 34/750 to 82/065 (2) Dharmabad–Balapur–IIIT up to state border section km 0/00 to 5/715	27.380	Nanded
12	EPC 21	Construction of major bridge including approaches over a local Nala near Pimpaldoh Village on Kalyan Nagar–Pathridi–Parbhani–Nanded–Bhokar–Maisha–Nirmal Road NH-61 (222)	0.950	Nanded
13	EPC 22	Ranjani–Kumbharpimpalgaon–Rajatakali (SH-222) km 173/0 to 216/0 Section 177/400 to 216/00 Section I of SH-222 just after the railway level crossing LC No. 89 (Kumbhar Pimpalgaon) Section II from existing km 205/750(SH 222) Kumbhar Pimpalgaon to Rajatakli existing km 216/000	37.415	Jalna

No.	Package No.	Connectivity/Activity (Improvement/Reconstruction/Widening)	Length (km)	District Location
14	EPC 23	Pusesavali Vangi Nagathane Walawa Borgaon Bahe Tambae Kasewgaon Takave Road SH-158 section from Vangi to Walawa km 24/470 to 70/00 (Section 28/470 to 70/00) and 0.340 m approach road	41.33	Sangli
15	EPC 24	Pusesavali Vangi Nagathane Walawa Borgaon Bahe Tambavi Kasewgaon Takave Road SH-158 Section from Walawa to Wakyrde kh km 70/00 to 117/250 (Section 70/00 to 112/620) in Tal. Walwa	42.62	Sangli
16	EPC 25	SH 54 Road from Pune district border to Diskal–Bhigwan–Madanwadi–Shetphalgade–Jainakwadi–Lamjewadi– Vanjarwadi–Baramati MIDC–Baramati Road–section of SH-54 from km 145/000 to 173/200 (Length 28.20 km)	28.20	Pune
17	EPC 26	Bari to Ghoti Sinnar Road (km 191/980 to km 205/300)	13.32	Nasik

EPC = engineering, procurement, and construction, km = kilometer, m = meter, SH = state highway.
Source: Maharashtra Public Works Department (3 February 2022).

B. Climate Change Policy of Maharashtra

6. Following directives from the central Government of India, the Government of Maharashtra state commissioned the process of drafting the State Action Plan on Climate Change (MSAPCC-2018). The Department of Environment of Maharashtra in collaboration with Action on Climate Today (ACT)[2] drafted the first state climate change policy, which was approved by the State Cabinet in 2017. The policy presents a framework for each sector to initiate climate change mainstreaming into their plans and budgets. With overall strategic guidance from the State Council for Climate Change of Maharashtra, the Climate Cell within the Environment Department coordinates and leads the state in the implementation of climate change policies and programs.

7. The climate document MSAPCC-2018[3] underscores the importance of climate change mitigation and adaptation and the need to act now, noting that weather patterns have changed dramatically in the state over the past decade, and that climatic transformation has triggered floods and landslides with greater frequency besides raising temperatures during the summer months and reducing the number of winter days. The five priority sectors identified for urgent action are (i) energy, (ii) agriculture, (iii) industries, (iv) transport, and (v) urban development.

II. CLIMATE CHANGE RISKS AND VULNERABILITY

A. Sector Climate Risk and Vulnerability

8. Scientific evidence shows that the warming of the global climate system is unambiguous; global average temperatures are higher than they were in past centuries, and they continue to increase. As a result, seas and oceans are warming, polar ice caps, and high elevation glaciers in mountainous regions are melting, sea levels are rising, and there are more varied and extreme weather patterns. Climate-related risks are created by a range of natural hazards driven primarily by long-term changes in temperature and precipitation. Overall, temperatures will be on average higher, there will be more incidents of record hot weather, precipitation levels and flooding risks will be higher, and more frequent, and more severe extreme weather events are projected to increase with global warming and climate change.

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[2] ACT is a program funded by the UK Department for International Development.
[3] The Energy Research Institute (TERI). 2014. *Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra: Maharashtra State Adaptation Action Plan on Climate Change*.

9. Climate change vulnerability is defined by the Intergovernmental Panel on Climate Change (IPCC) as the susceptibility of a species, system, or resource to the negative effects of climate change and other stressors, and is described in terms of association between exposure, sensitivity, and adaptive capacity. Exposure is the amount and rate of change that a species or system experiences from both direct and indirect impacts of climate change. Sensitivity refers to characteristics of a species or system that are dependent on specific environmental conditions, and the degree to which it will likely be affected by climate change. Adaptive capacity is the ability of a species or system to cope and persist under changing conditions through local or regional acclimation, dispersal or migration, adaptation, and/or evolution.

10. Road transport organizations around the world draw attention to the impact of climate change on road infrastructure integrity and performance and the necessity for appropriate mitigation and adaptation measures. Road infrastructure and operations are exposed to severe risks as a result of increase in frequencies and intensities of extreme weather events brought about by climate change. Some generic impacts of climate change on road infrastructures/assets as briefly outlined below call for a rethink about how roads are designed, constructed, and maintained to achieve lasting benefits.

(i) Changes in rainfall, temperature, and evaporation patterns can alter the moisture balances in road embankments and pavements.
(ii) Rise in the water table can lead to the reduction of the structural strength of the road pavement, leading to damages to earthworks, embankments, and drainage systems.
(iii) Rise in air temperature and temperature extremes can accelerate the aging of road surfacing bitumen layers, leading to surface cracking, migration of asphalt and rutting, and increased rate of wear and tear.
(iv) Rise in temperature extremes impacts on concrete construction practices, including thermal expansion of bridge expansion joints.
(v) Increase in precipitation and in intense precipitation events can cause overloading of drainage systems, causing backups and flooding, and increases in road washouts.
(vi) Changes in seasonal precipitation and river flow patterns induce increased risk of floods from runoff, landslides, slope failures, and damage to roads, and bridges.
(vii) Storms and more frequent strong cyclones can bring about increased road flooding, greater probability of infrastructure failures, erosion of road base and bridge supports, bridge scour, reduced clearance under bridges, and wind damage to signs, lighting, signs, overhead cables, road signals, and tall structures.

B. Climate Risks Assessment – the Rationale

11. It is universally recognized that climate change in the long run might produce new kinds of hazards and threats to infrastructure. Therefore, tackling climate change impacts involves strengthening and/or improving upon the already known deficiencies. Since 2010, ADB has defined its priorities for action that include assisting developing member countries in climate-proofing of projects to ensure their outcomes are not compromised by climate change and variability or by natural hazards in general. A climate risk management approach has been adopted by ADB in an increasing significant number of investment projects.

12. ADB recognizes that development is about lasting benefits. Hence, a climate risk and adaptation assessment (CRA) is done during the project preparation phase that examines climate change events and risks and, where technical and economically feasible, mitigation, and adaptation measures are appropriately assessed and implemented. Based on the level of climate change risks for the project and the mitigation and/or adaptation measures incorporated in the

project design, the associated climate change costs are determined. The CRA is a collaborative process that examines and informs project teams and stakeholders about future climate risks that can affect the performance of an investment project.

13. ADB has institutionalized a framework[4] in response to the mandated requirement that exposure and vulnerability to climate change risks be identified and accounted for in the preparation of transport projects. The framework encourages a sequential process to assess climate change vulnerability and impacts, and to identify mitigation, and adaptation needs and options.

14. Adaptation options in the transport sector may generally be grouped into engineering (structural) options and non-engineering options. It is also possible that a decision not to act, or to maintain a business-as-usual approach ("do nothing" option), can be retained as a possible option. In some circumstances driven by a host of uncertainties primarily because of information gaps, conclusions from the impact, vulnerability, and adaptation assessments may indicate that doing nothing (no climate-proofing) could be the best course of action (footnote 4).

15. Non-engineering options of climate change relate to a process of adjusting to changing climate and its cascading impacts on the local environment and are examined in the project environmental reports. The initial environmental examination (IEE) addresses biophysical drivers of vulnerabilities such as unwholesome land management practices, deforestation, and detrimental agricultural, and cropping patterns. Furthermore, the IEE screenings and assessments expose geophysical vulnerabilities such as slope instability, erosion, flood risks, etc. and recommend that adequate risk mitigation or adaptation measures are undertaken during the project design.

C. Scope, Methodology, and Limitations

16. The scope of this CRA pertains to looking at aspects of engineering adaptation and mitigation measures against climate change risks with focus on temperature and precipitation-induced vulnerabilities and their secondary impacts. These aspects include road assets such as road embankment and pavement, drains, culverts, and bridges, slope and flood protection structures, and mitigation strategies such as relocation, realignment, bioengineering, etc.

17. **Desk reviews.** Desk reviews for this project primarily included the detailed project reports and from among the numerous volumes covering all aspects of the CECIGM design. In particular, this CRA included reviews of (i) Volume I – Main Report, (ii) Volume II – Design Report, (iii) Volume V – Technical Specifications, and (iv) Volume VII – Cost Estimates.

18. Climate factors manifest their effects in a multitude of ways that make climate-proofing a challenging activity given the complexities and uncertainties of the factors that define climate risks and vulnerability, particularly at a project scale. Although the impacts of climate change are widely recognized, gaps exist in guidance materials and information resources that are necessary to identify to facilitate the climate-proofing of investment projects within the region.[5] There is also no clear and universally adopted methodology to model the adverse effects of climate change and its integration in infrastructure design procedures.

19. As climate change adaptation and mitigation measures for the CECIGM project are based

[4] ADB. 2014. *Climate Proofing ADB Investment in the Transport Sector, Initial Experience*. Manila.

[5] ADB. August 2011. Guidelines for Climate-Proofing Investment in the Transport Sector. Road Infrastructure Projects. Manila.

primarily on desk reviews, the CRA will certainly contain a large number of important qualification and limitation issues. Deficient assessments of climate risks particularly at a project scale, interpretation of vulnerabilities and impacts, and application, and adequacy of mitigation and adaptation measures in terms of climate-proofing, affect the final assessment.

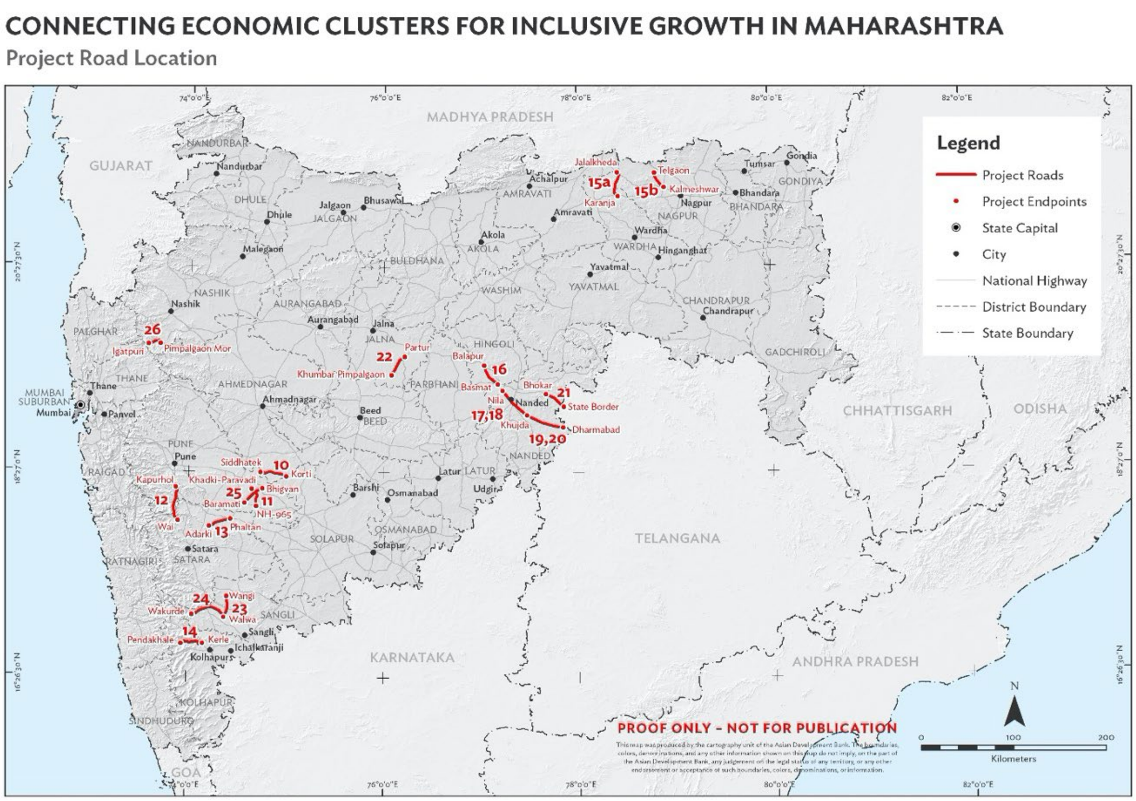
III. PROJECT AREA, CLIMATE, AND CLIMATE CHANGE

A. CECIGM Project Locations

20. Depending on relief, topography, and climatic and vegetative characteristics, Maharashtra is composed of several distinct physiographic traits, the predominant being the plateau lying to the east of Sahyadri (Western Ghats) range. The Sahyadri is a chain of mountains with an average height of 1,200 meters above mean sea level (amsl), oriented in a north–south direction. The Konkan coastal region is the narrow tract of lowland between Sahyadri and the Arabian Sea, with average altitude ranging from sea level to about 200 amsl. The Maharashtra plateau, also known as the Deccan Plateau, ranges from 500–1,000 meters in elevation and this tableland is composed of old and stable landmass characterized by accumulation of volcanic rocks, principally basaltic lavas. Major rivers originating from the Sahyadri range such as Bhima, Godavari, Krishna, and Tapi, and their numerous tributaries have defined the plateau into broad river valleys.

21. The 18 CECIGM packages are scattered in various districts of Maharashtra with varying physiographic and climatic variations. Figure 1 shows the locations of districts in which the project roads are situated according to physiographic relief.

Figure 1: Project Corridors by Physiographic Relief

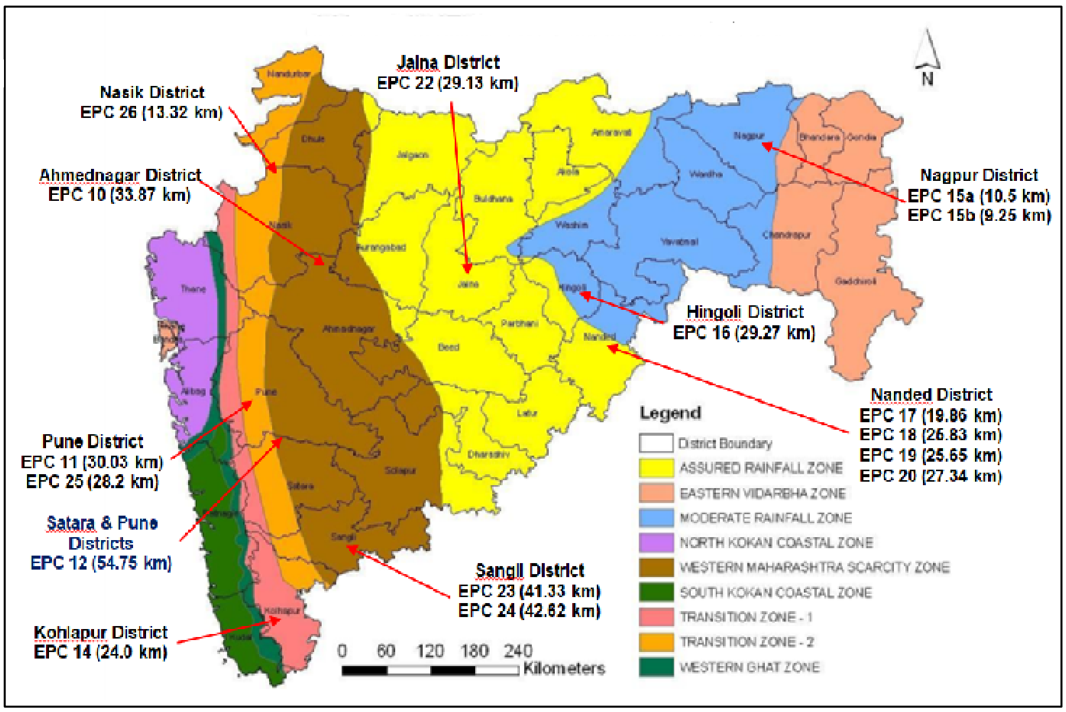


Source: Asian Development Bank.

22. Differentiated by rainfall, soil, and cropping patterns, the state of Maharashtra is categorized into nine agro-climatic zones.[6] The zones of interest with regard to CECIGM are as follows: (i) Transition Zone I: a narrow strip of low elevation land in the eastern side of the Sahyadri range. Rainfall varies widely from 700 to 2,500 millimeters (mm)/year depending on the southwest monsoon. Summer maximum temperatures vary from 28°C to 35°C; (ii) Transition Zone II: mostly a plain strip of land running north–south parallel to the eastern side of Transition Zone I. Rainfall varies from 700 to 1,200 mm/year well distributed during the southwest monsoon. The maximum temperature reaches to as high as 40°C in the summer; (iii) Western Maharashtra Scarcity Zone: a drought-prone zone characterized by low and unpredictable rainfall of 500 to 700 mm/year with dry spells lasting from 2 to 10 weeks. Summer temperatures reach above 42°C; (iv) Assured Rainfall Zone: where rainfall of 700 to 900 mm/year is distributed as dictated by the southwest monsoon. Maximum summer temperature reaches to about 40˚C; and (v) Moderate Rainfall Zone: where rainfall of 1,200 mm/year is well distributed within the southwest monsoon months. Maximum temperatures reach 35°C–40°C in summer.

23. Figure 2 shows the climatic zones of Maharashtra and the districts in which the project roads are located.

Figure 2: Project Corridors by Climatic Zones



EPC = engineering, procurement, and construction, km = kilometer.
Source: Base Map.

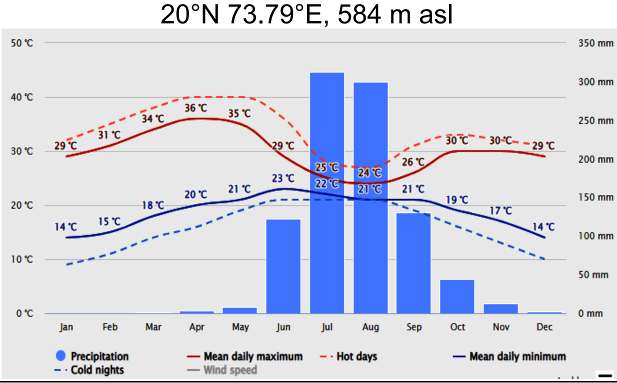
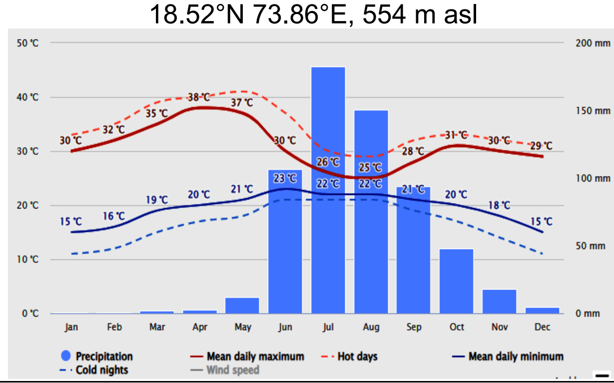
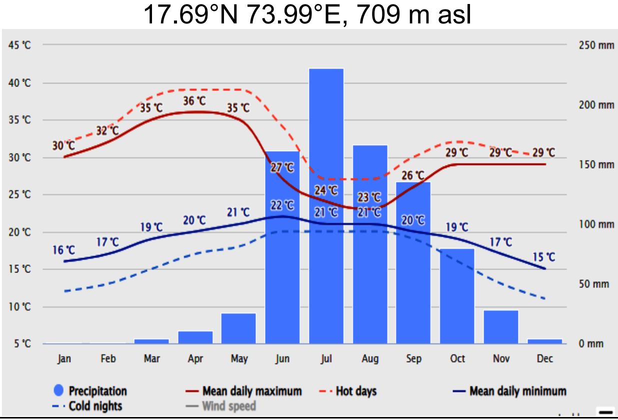
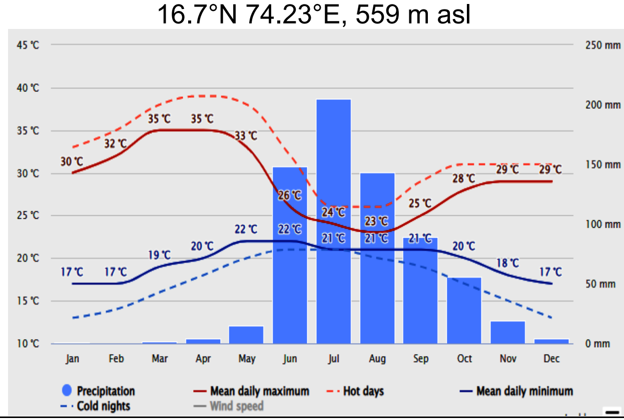
[6] Maharashtra Water Sector Improvement Project, Department of Agriculture, Maharashtra.

B. The Baseline Climate

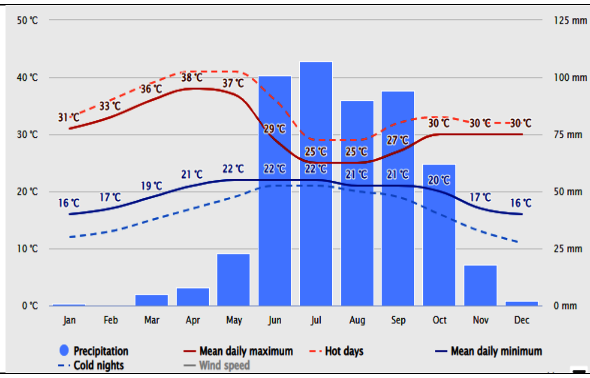
24. The following information are extracts from sources available online. Meteoblue-Data.org offers climate information on its website and the meteoblue climate diagrams presented in Figure 3 are based on 30 years of past weather data and model simulations. [7] They give good indications of typical climate patterns and expected conditions (temperature, precipitation, sunshine, and wind). The simulated weather data have a spatial resolution of approximately 30 km and do not reproduce all local weather effects, such as thunderstorms, local winds, or cyclones.

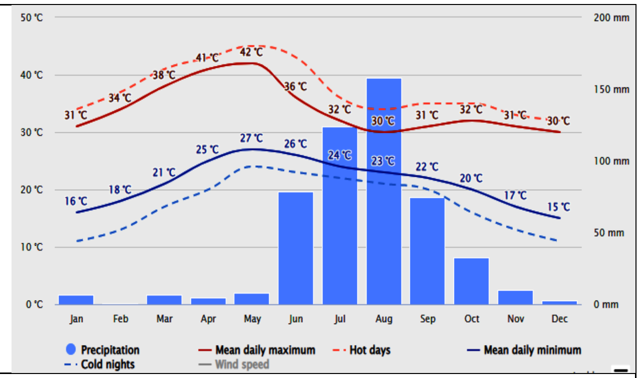
25. Figure 3 illustrates average monthly baseline information in terms of two important climatic variables—temperature and precipitation—for representative districts where the CECIGM subproject roads are located. The "mean daily maximum" (solid red line) shows the maximum temperature of an average day for every month for the project districts. Likewise, "mean daily minimum" (solid blue line) shows the average minimum temperature. Hot days and cold nights (dashed red and blue lines) show the average of the hottest day and coldest night of each month of the last 30 years.

Figure 3: Average Monthly Temperature and Precipitation by Project Districts

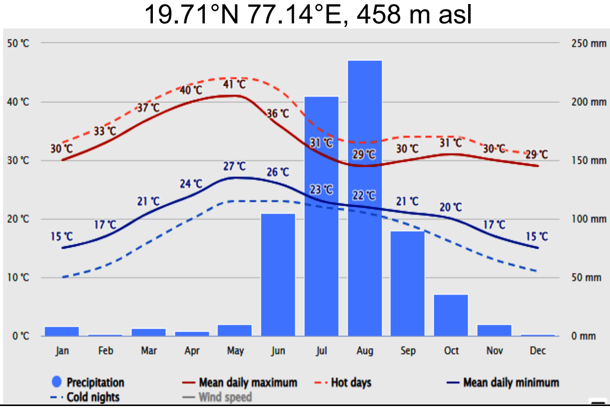
<table>
<tr><td>Nasik
20°N 73.79°E, 584 m asl

</td>
<td>Pune
18.52°N 73.86°E, 554 m asl

</td></tr>
<tr><td>Satara
17.69°N 73.99°E, 709 m asl

</td>
<td>Kolhapur
16.7°N 74.23°E, 559 m asl

</td></tr>
<tr><td>Sangli
16.85°N 74.56°E, 553 m asl</td><td>Nanded
19.16°N 77.32°E, 363 m asl</td></tr>
</table>

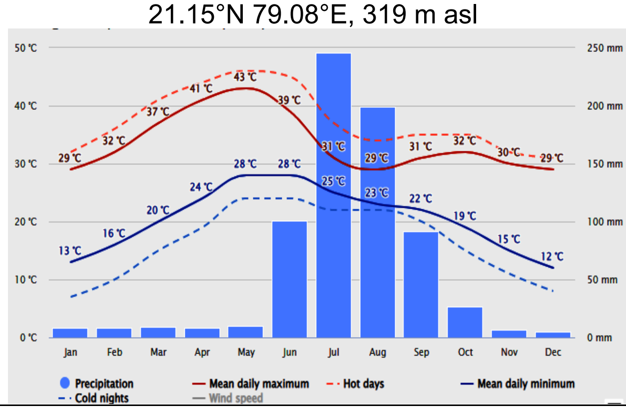
[7] Meteoblue. Climate diagrams (accessed March 2022).



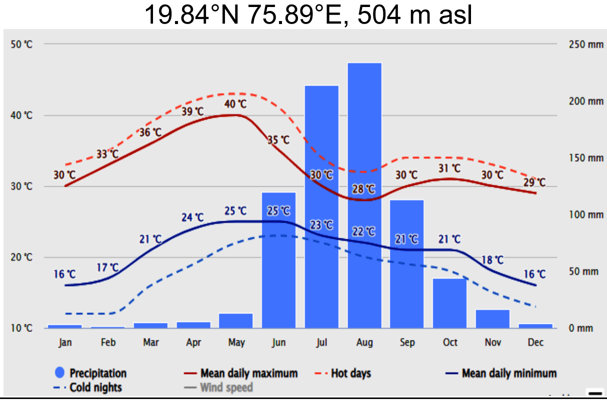


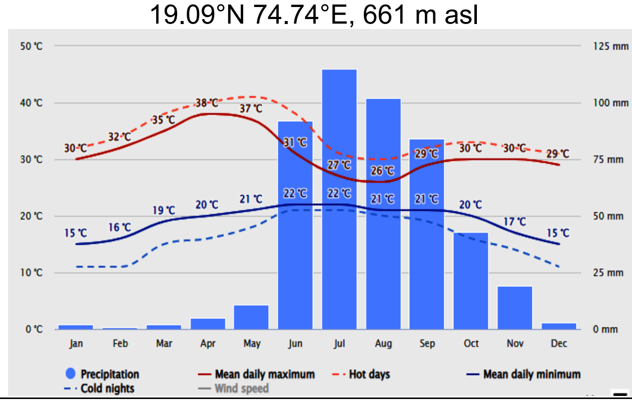
Hingoli 19.71°N 77.14°E, 458 m asl	Nagpur 21.15°N 79.08°E, 319 m asl





Jalna 19.84°N 75.89°E, 504 m asl	Ahmednagar 19.09°N 74.74°E, 661 m asl





ASL = above sea level, m = meter.
Source: Meteoblue.

C. Observed Climate Trends

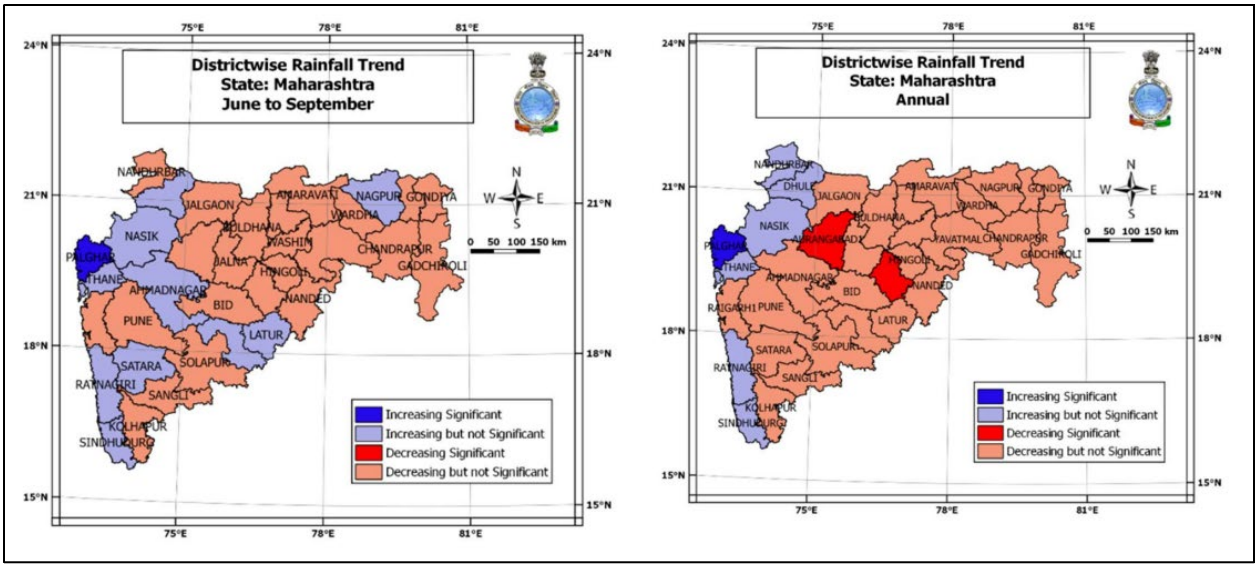
26. The Indian Meteorological Department (IMD) in its 2020 monograph presents the analysis of observed rainfall patterns, trends, and variability over Maharashtra state based on the past 30 years (1989–2018).[8] The monograph intends to help provide an idea of the recent changes for climate change adaptation and management by the state authorities. Maharashtra receives more than 89% of annual rainfall during the southwest monsoon season in June, July, August, and September (JJAS). About 33% of the southwest monsoon rainfall occurs in July, about 28% in

[8] Government of India, Ministry of Earth Sciences. 2020. *Observed Rainfall Variability and Changes over Maharashtra State*. Pune.

August, about 21% in June, and about 18% in September.

27. In terms of total JJAS monsoon rainfall, the following trends were observed in the project districts as (i) increasing though not significant in Ahmednagar, Nagpur, Nashik, and Satara; and (ii) decreasing though not significant in Jalna, Hingoli, Kolhapur, Nanded, Pune, and Sangli. In terms of total annual rainfall, the following trends were observed in the project districts as (i) increasing though not significant in Nashik, and (ii) deceasing but not significant in the rest of the project districts. (Figure 4)

Figure 4: District-wise Total Rainfall Trend (1989–2018)



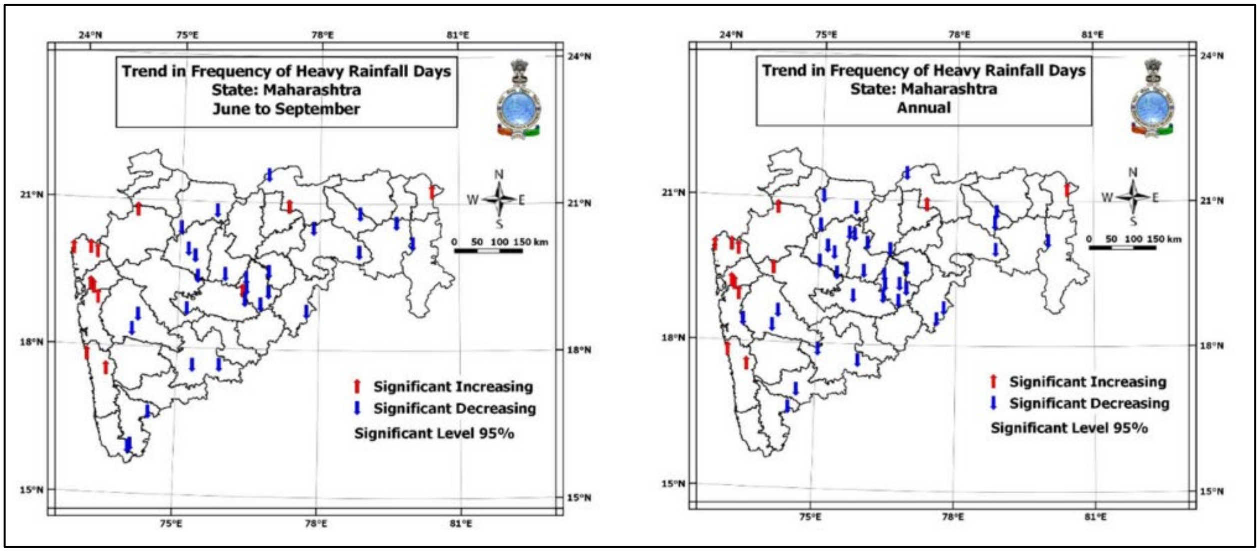
Source: Indian Meteorological Department, Pune.

28. During the monsoon, the maximum number of rainy days (daily rainfall >2.5 mm) lies in the range of 62 to 70 days and occurs in some parts of Kolhapur district. The number of rainy days in some parts of Ahmednagar, Hingoli, Jalna, Nanded, and Nashik districts fall in the range of 28 to 37 days. The remaining districts of Nagpur, Pune, Sangli, and Satara experience rainy days in the range of 37 to 62 days.

29. During the monsoon, the maximum number of heavy rainfall (daily rainfall >10 mm) days lies in the range of 9 to 11 days especially in some parts of Kolhapur district. Heavy rainfall days in the range of 1 to 3 days occur in some parts of Ahmednagar, Hingoli, Jalna, Nagpur, Nanded, Nashik, and Satara districts. In the remaining project districts of Pune and Sangli, the number of heavy rainfall days lies in the range of 3 to 9 days.

30. In terms of frequency of very heavy rainfall days during JJAS monsoon season, a significant decreasing trend in heavy rainfall days is seen in the project districts of Ahmednagar, Hingoli, Jalna, Kolhapur, Nanded, and Pune while the remaining project districts did not show any significant change. In terms of annual frequency of heavy rainfall days, there is a significant decrease in heavy rainfall days in Ahmednagar, Hingoli, Jalna, Kolhapur, Nanded, and Pune, while the remaining project districts did not show any significant change (Figure 5).

Figure 5: Trend in the Frequency of Heavy Rainfall Days



Source: Indian Meteorological Department, Pune.

D. Trends in Extreme Rain Events

31. Despite the decrease in mean annual rainfall, a recent study finds a threefold increase in widespread extreme rain events over central India during 1950–2015.[9] The decline in the mean rainfall is attributed to a weakening monsoon circulation, owing to a combination of factors including the warming of the Indian Ocean, increasing frequency and magnitude of El Niño events, increased air pollution, and land use changes over the subcontinent. The monsoon variability has amplified in the recent decades, resulting in a phenomenal rise in extreme rainfall events.

32. The above study notes that the low-level monsoon westerlies over the northern Arabian Sea exhibit increasing variability, driving surges of moisture supply, leading to extreme rainfall episodes across the entire central subcontinent. The time series of the mean summer monsoon rainfall during 1950–2015 was observed to have declined by 10% as averaged over the central Indian region, with 20%–30% decrease over some of the grid points. However, the frequency of extreme rainfall events (daily rainfall ≥ 150 mm) over central India had increased by about 75% during the same period (significant at 95% confidence level). As such, extreme events are on the rise at a rate of about 13 events per decade, which is more than one per year. Furthermore, the study notes that it is not only the frequency of extreme rain events that is increasing, but the extremes are also intensifying over time as observed by an increase in the 99.5th percentile values. The increase in extreme rainfall while the mean rainfall is decreasing also implies that the dry spells (droughts) may be increasing in this region.

E. Future Climate Projections for Maharashtra

33. The future projections for Maharashtra state as outlined here are those obtained from the Climate Change Knowledge Portal (CCKP) developed by the World Bank where different projected climatologies and emission scenarios, or Shared Socioeconomic Pathways (SSP), are

[9] M. K. Roxy et al. 2017. A threefold rise in widespread extreme rain events over central India. *Nature Communications*. 8 (708). Springer Nature.

considered.[10] In the CCKP page, projection data are presented as multi-model ensembles that represent the range and distribution of the most plausible projected outcomes of change in the climate system for a selected SSP.[11]

34. The CCKP climate projection provides modeled data from the global climate model compilations of the Coupled Model Intercomparison Projects (CMIP) overseen by the World Climate Research Program. Data presented are CMIP6, derived from the sixth phase of the CMIPs, that form the data foundation of the IPCC Assessment Reports. CMIP6 supports the IPCC's Sixth Assessment Report.[12] Projection data are presented at a 1.0º x 1.0º (100 km x 100 km) resolution.

35. The SSPs are new climate change scenarios introduced recently in the IPCC Sixth Assessment Report and are meant to provide insight into future climates based on defined emissions, mitigation efforts, and development paths. The SSP scenarios depend on how quickly humans curb greenhouse gas emissions. This depends on socioeconomic changes in areas such as population, urban density, education, land use, and wealth. For example, a rise in population is assumed to lead to higher demand for fossil fuels and water resources. Education can affect the rate of technology developments. Emissions increase when land is converted from forest to agricultural land.

36. The SSP number x is combined with the expected radiative forcing (representative concentration pathway [RCP]) y.z to arrive at a scenario SSPx-y.z as given in Table 3.

Table 3: **Shared Economic Pathways**

SSP No.	Scenario (Likelihood)	Estimated Warming, °C		Very Likely Range, °C
		2041–2060	**2081–2100**	**2081–2100**
SSP1-1.9	Very low GHG emissions: CO_2 emissions cut to net zero around 2050	1.6	1.4	1.0 – 1.8
SSP1-2.6	Low GHG emissions: CO_2 emissions cut to net zero around 2075	1.7	1.8	1.3 – 2.4
SSP2-4.5	Intermediate GHG emissions (likely): CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0	2.7	2.1 – 3.5
SSP3-7.0	High GHG emissions (unlikely): CO_2 emissions double by 2100	2.1	3.6	2.8 – 4.6
SSP5-8.5	Very high GHG emissions (highly unlikely): CO_2 emissions triple by 2075	2.4	4.4	3.3 – 5.7

C = centigrade, CO_2 = carbon dioxide, GHG = greenhouse gas, SSP = Shared Socioeconomic Pathway.
Source: Shared Socioeconomic Pathways.

37. In every scenario, warming continues and how extreme the weather might get depends on which path the world opts to take. There is no telling which scenario is most likely—that will depend on many complicated factors including government policies, but it does show how choices today will affect the future.

38. SSP1-1.9 is the IPCC's most optimistic scenario that describes a world where global CO_2

[10] World Bank, Climate Change Knowledge Portal.
[11] Government of India, Ministry of Earth Sciences. 2020. *Observed Rainfall Variability and Changes over Maharashtra State*. Pune.
[12] IPCC Sixth Assessment.

emissions are cut to net zero around 2050. In this scenario, societies switch to more sustainable practices, with focus shifting from economic growth to overall well-being, with higher investments in education and health and fall in inequality. This first scenario is the only one that meets the Paris Agreement's goal of keeping global warming to around 1.5°C above preindustrial temperatures, with warming hitting 1.5°C but then dipping back down and stabilizing around 1.4°C by the end of the century.

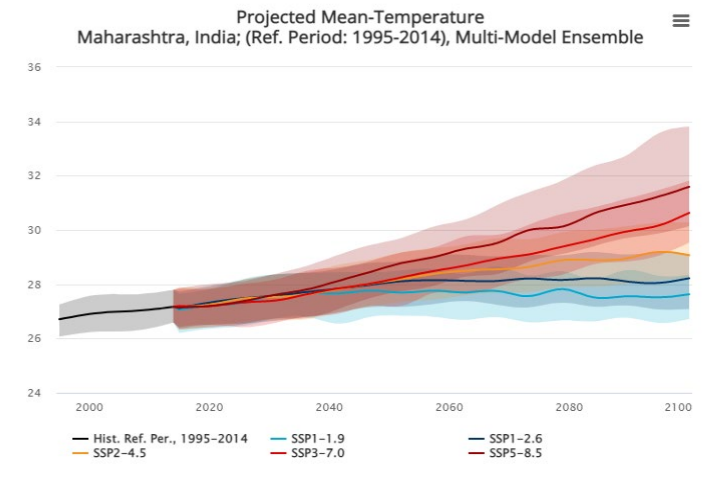
39. SSP5-8.5 is the worst-case scenario where CO_2 emissions levels roughly double by 2050. The global economy grows quickly, but this growth is fueled by exploiting fossil fuels and energy-intensive lifestyles. By 2100, the average global temperature is 4.4°C higher.

40. The CCKP page offers a selection of the most popular climate indicators under various SSP scenarios presented through multi-model ensembles. The projected data for Maharashtra presented in the following tables are given for the SSP2-4.5 scenario, which is a sort of a "middle of the road" scenario in which CO_2 emissions hover around current levels before starting to fall mid-century, but do not reach net zero by 2100. Socioeconomic factors are envisaged to follow their historic trends, with no notable shifts. In this scenario, the very likely range of temperature change is 2.1°C to 3.5°C by the end of the century.

41. The SSP2-4.5 projections of temperature and rainfall extracted here are for a few selected climate indicators of interest as follows:

(i) Mean temperature – Figure 6
(ii) Maximum of daily max temperature – Figure 7
(iii) Days with heat index >35°C – Figure 8
(iv) Precipitation percentage change – Figure 9
(v) Average largest 1-day precipitation – Figure 10
(vi) Average largest 5-day cumulative rainfall – Figure 11

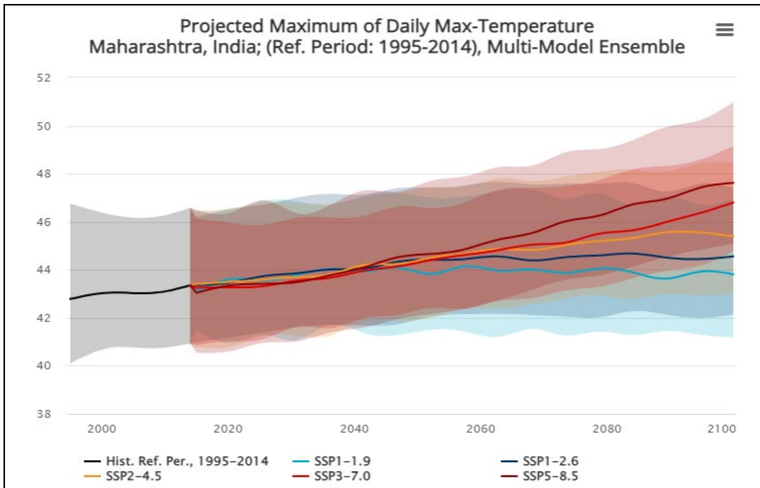
Figure 6: Projected Mean Temperature



SSP2-4.5	50th Percentile (median)	10th to 90th Percentile Range
	(°C)	
2030	27.52	26.67 – 28.33
2040	27.76	26.89 – 28.63
2050	28.12	27.29 – 29.07
2060	28.45	27.50 – 29.38
2070	28.57	27.70 – 29.69
2080	28.91	27.91 – 29.95

C = centigrade, SSP = Shared Socioeconomic Pathway.
Source: Climate Change Knowledge Portal.

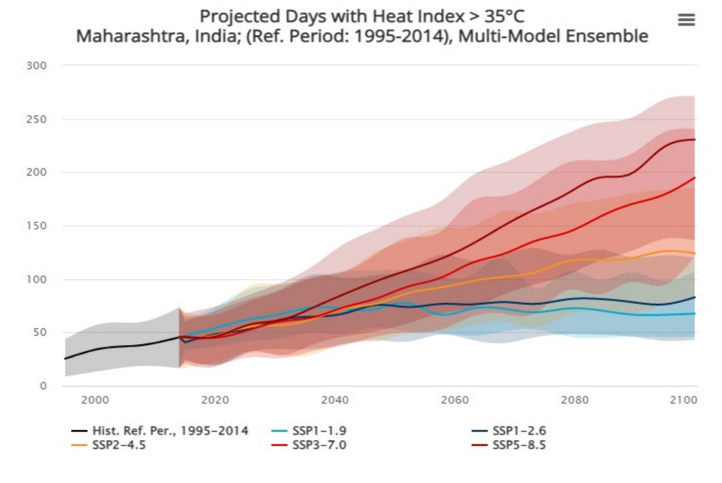
Figure 7: Projected Maximum of Daily Maximum Temperature



SSP2-4.5	50th Percentile (median)	10th to 90th Percentile Range
	(°C)	
2030	43.69	41.29 – 46.81
2040	44.11	41.74 – 46.94
2050	44.38	41.89 – 47.37
2060	44.78	42.40 – 47.63
2070	44.87	42.65 – 47.72
2080	45.22	42.91 – 48.12

C = centigrade, SSP = Shared Socioeconomic Pathway.
Source: Climate Change Knowledge Portal.

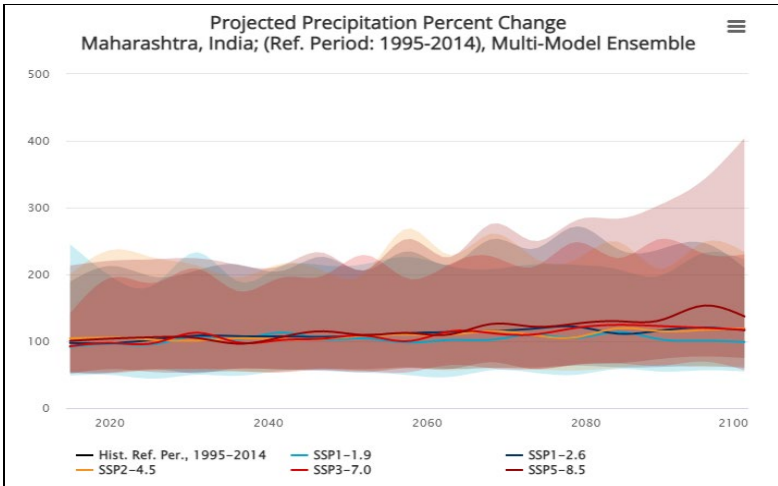
Figure 8: Projected Days with Heat Index >35°C



SSP2-4.5	50th Percentile (median)	10th to 90th Percentile Range
	(Days)	
2030	56.48	29.91 – 95.46
2040	69.86	36.81 – 103.87
2050	82.57	45.66 – 132.23
2060	94.61	53.50 – 147.86
2070	102.84	57.62 – 163.85
2080	117.68	68.58 – 171.02

C = centigrade, SSP = Shared Socioeconomic Pathway.
Source: Climate Change Knowledge Portal.

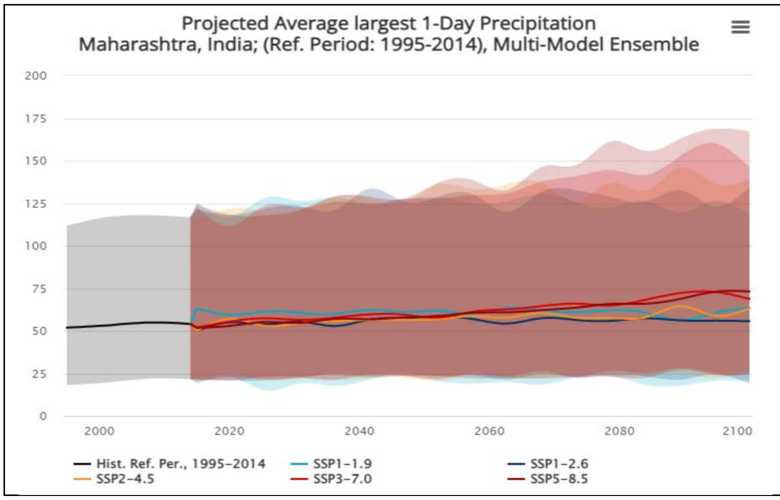
Figure 9: Projected Precipitation Percentage Change



SSP2-4.5	50th Percentile (median)	10th to 90th Percentile Range
	(%)	
2030	100.57	57.49 – 216.68
2040	103.54	53.16 – 219.14
2050	106.39	57.63 – 193.12
2060	109.43	58.61 – 253.42
2070	114.36	60.36 – 255.64
2080	108.75	56.85 – 231.08

SSP = Shared Socioeconomic Pathway.
Source: Climate Change Knowledge Portal.

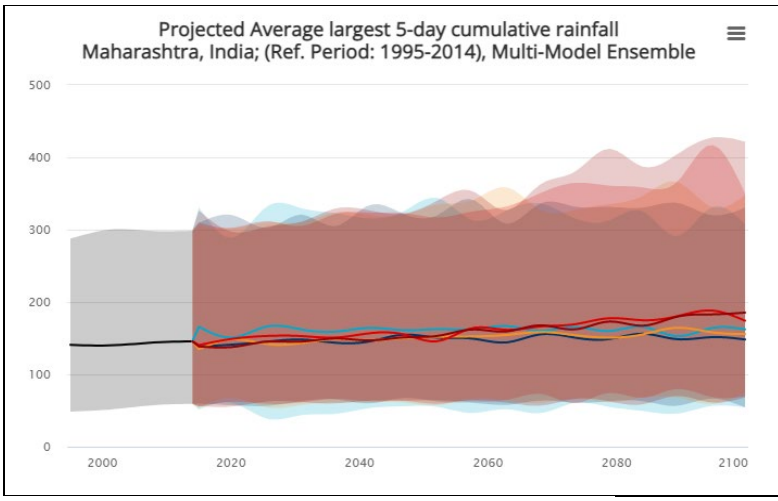
Figure 10: Projected Average Largest 1-Day Precipitation



SSP2-4.5	50th Percentile (median)	10th to 90th Percentile Range
	(mm)	
2030	54.2	21.73 – 120.95
2040	56.23	21.56 – 128.89
2050	56.48	20.86 – 131.98
2060	58.09	24.67 – 133.63
2070	59.86	23.23 – 132.05
2080	57.34	23.11 – 136.61

mm = millimeter, SSP = Shared Socioeconomic Pathway.
Source: Climate Change Knowledge Portal

Figure 11: Projected Average Largest 5-day Cumulative Rainfall



SSP2-4.5	50th Percentile (median)	10th to 90th Percentile Range
	(mm)	
2030	142.19	56.29 – 309.32
2040	147.67	61.10 – 322.29
2050	151.43	57.89 – 329.74
2060	152.93	67.01 – 353.08
2070	157.77	62.68 – 322.85
2080	150.93	61.98 – 336.56

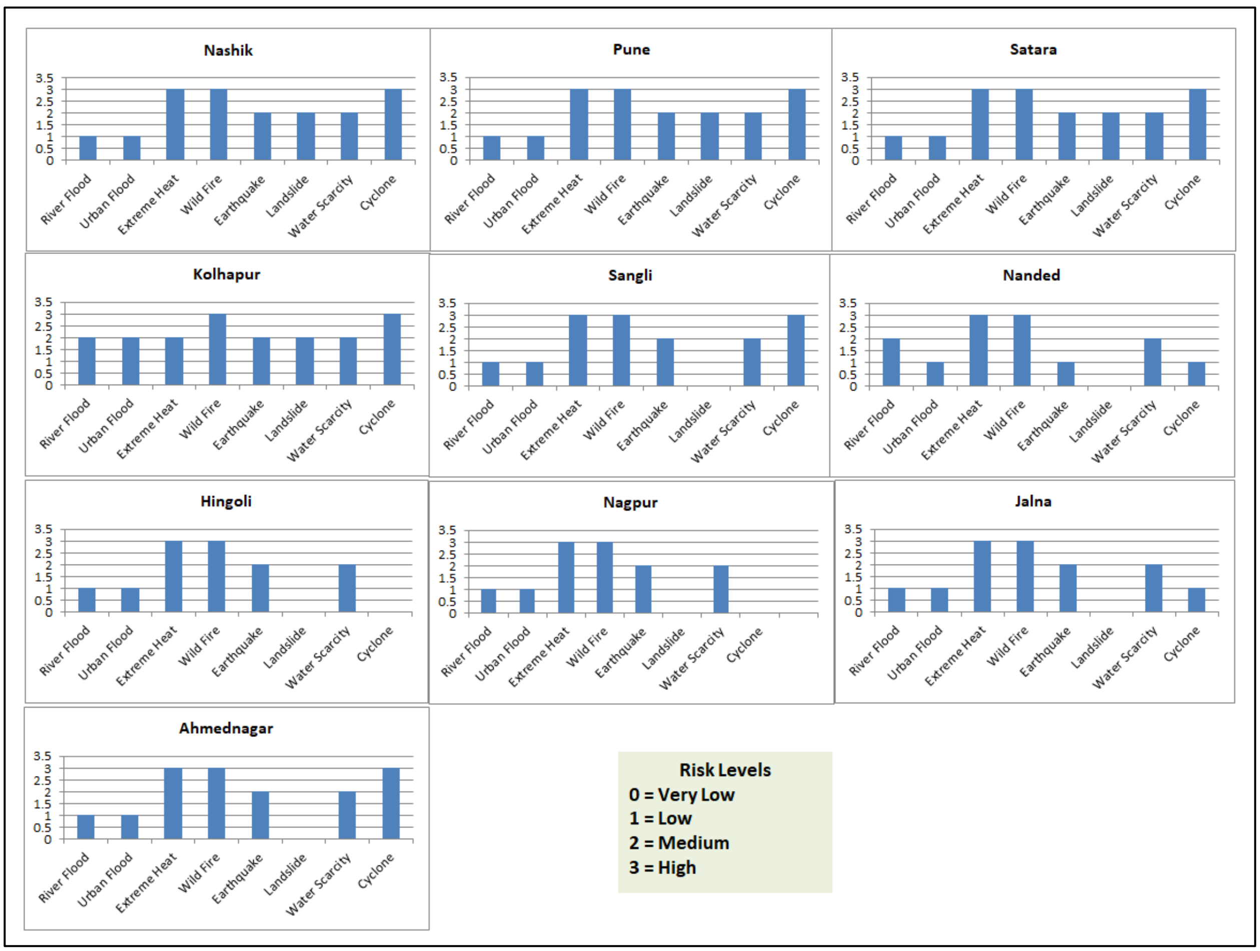
mm = millimeter, SSP = Shared Socioeconomic Pathway.
Note: The average precipitation projections by climate models should be approached cautiously. There are about 40 different climate models within CMIP5 that provide estimates of precipitation changes in the future. Unlike for temperature, where models show a general degree of agreement about future regional changes, different models may have the same region becoming much wetter or much drier in a warming world. Climate models are not perfect, and projections of future average precipitation changes may become more consistent as models continue to improve.
Source: Climate Change Knowledge Portal.

III. CLIMATE-RELATED NATURAL HAZARDS AND OUTLOOKS ON ADAPTATION

A. Hazards and Likelihood Assessment, CECIGM

42. The state of Maharashtra with its diverse physiography and climate and ecosystem variations is prone to assortments of climate-related natural risks such as extreme heat, wildfires, droughts, cyclones, floods, landslides, and geophysical risks such as earthquakes. A general perspective of the prevalence of natural hazards and associated levels of risks in the project districts as presented in Figure 12 are the products of a web-based tool, *ThinkHazard*.[13] This tool enables non-specialists to consider the impacts of disasters on new development projects as it quickly provides a general view of the hazards for a given location that could be considered in the project design and implementation to promote disaster and climate-resilience. The hazard levels provided in this tool are said to be based on published hazard data, provided by a range of private, academic, and public organizations.

Figure 12: Likelihood of Natural Hazards in CECIGM Project Districts



CECIGM = Connecting Economic Clusters for Inclusive Growth in Maharashtra.
Source: ThinkHazard.

[13] ThinkHazard!: Developed for informational purposes by the Global Facility for Disaster Reduction and Recovery (GFDRR).

B. Vulnerability and Risks

1. Extreme Heat

43. The mean maximum temperatures during the pre-monsoon months of March, April, and May as depicted in Figure 3 show that the 10 project districts regularly experience high maximum temperatures ranging from 38°C to as high as 45°C. Projected climate changes (Figure 7) are expected to push temperatures above 40°C on a regular basis. As such, the risks of extreme heat will continue to be high in all project districts.

44. High temperatures and heat waves are a cause of concern impacting road pavement integrity, causing road surface failures by softening, and traffic load rutting and cracking. It is also recognized that oxidation and the action of ultraviolet (UV) radiation cause excessive hardening of the asphalt close to the pavement surface and the material to become brittle over time. Hotter weather will speed up oxidation process and make the material more vulnerable to cracking, and cooler diurnal temperatures will generate thermal tensile stresses that cause crack initiation and propagation.

45. Bridges are subjected to daily, seasonal, and yearly repeated cycles of heating and cooling induced by solar radiation and surrounding air. Temperatures affect bridges with expansion/contraction cycles due to temperature changes, and impacts bearings and expansion joints usually used to accommodate movements. These movements in the bridge may seem initially insignificant, but with pervasive changes induced by extreme heat (Figure 8), the bridge may eventually start to deform and fail.

2. Flood

46. Floods associated with heavy to extreme rainfall events and/or continuous days of heavy rainfall are a frequent phenomenon in many parts of India, including Maharashtra, that impacts vast tracts of land almost every year. Floods cause immense human hardship resulting from submergence of land, collapse of buildings/houses, and extensive damages to property, and further adversely impact lifeline infrastructures such as roads, railways, telecommunication lines, dams and reservoirs, etc.

47. The physiographic and orographic effects of the Sahyadri mountain range of Maharashtra greatly influence the spatial distribution of southwest monsoon precipitation, making the state vulnerable to the impacts of flood, tropical cyclones, and storm surges in the coastal belt. Most of the project districts lie in the leeward side of the state and the exposure and vulnerability to the effects of extreme precipitation vary with location. The level of risks posed by river flooding is indicated as *low* in most of the project districts except in Kolhapur and Nanded where river flooding risks are *medium*. According to ThinkHazard, low risk roughly translates to a chance of more than 1% of potentially damaging and life-threatening river floods occurring in 10 years. Medium risk translates to around 20% chance of potentially damaging and life-threatening river floods occurring in 10 years.

48. The risk levels on river flooding as provided in Figure 12 should be considered as preliminary in defining the river flood hazard level. It must be noted that river flooding is a local phenomenon that varies dramatically over short distances, depending on local topography and distance from the waterway. River floods are often devastating that impact surface transport

infrastructure and operations and as such, local assessment is necessary to identify (i) whether any sources of flooding such as streams and rivers exist, and (ii) whether the area is located within the floodplain. If they do, it would then be prudent to identify whether the project road may become flooded. Similarly, urban flooding is also low for most of the project districts except in Kolhapur with *medium risks*. It must be underscored that urban flooding has become a major source of socioeconomic threat to many cities in India in recent decades.

3. Tropical Cyclones

49. The Indian subcontinent is also exposed to nearly 10% of all tropical cyclones occurring globally. The cyclones usually occur during the months of May to June, and October to November, with a primary peak in November and May. Tropical cyclones are associated with extreme winds, high precipitation, and flooding, and are a grave concern for the populations in coastal areas and settlements located on delta plains or in the vicinity of rivers. In terms of cyclone risks, the project districts of Ahmednagar, Nashik, Pune, Sangli, and Satara are classified as *high* (Figure 12), meaning that there is more than a 20% chance of potentially damaging wind speeds in the project area in the next 10 years. However, according to the Indian Meteorological Department's data on cyclone-prone districts of India, only those districts of Mumbai, Ratnagiri, Raigarh, Sindhudur, and Thane in Maharashtra are categorized as *P3* or "moderately prone" based on frequency, severity, wind strength, and probable maximum precipitation.[14] As districts lie farther inland, risks of direct landfall impacts of cyclonic events weaken progressively.

50. According to a study on tropical cyclones and climate change, modeling of climate change impacts on cyclone intensity and frequency conducted across the globe points to a general trend of reduced cyclone frequency but increased intensity and frequency of the most extreme events.[15]

4. Landslides

51. Rainfall is one of the main triggering factors of landslides and those could be shallow landslides, surface and gully erosion, debris flows, mud slides, and debris slides. Among the districts where the project roads are located, Nashik, Pune, Satara and Kolhapur districts are exposed to landslide hazards but are medium in terms of levels of risk. (Figure 12) Here, only those roads that navigate across undulating hilly terrain in the Sahyadri (Western Ghats) range are susceptible to landslides as these areas are associated with rainfall patterns, terrain slope, geology, soil, and land cover that make localized landslides a hazard phenomenon.

52. Road construction activities inadvertently change the terrain at the toe of a slope, which compromise the continuity of water flow and reduce the ability of the slope to drain, in turn reducing its stability. Another reason are changes in the forest landscape or large-scale logging, which change the soil infiltration and ground evapotranspiration rates, thus indirectly affecting the water contents in soil and reducing slope stability. Furthermore, climate change is likely to alter slope and bedrock stability through changes in precipitation and/or temperature.

53. By Figure 12, almost all districts of interest are indicated to be vulnerable to medium earthquake risks. Earthquakes often trigger landslides, causing significant and even catastrophic damage to roads, leading to road closures for extended periods of time. Road construction works often weaken the shear strength of hillslope material, thus increasing landslide susceptibility of

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[14] Regional Specialized Meteorological Centre for Tropical Cyclones Over North Indian Ocean, Indian Meteorological Department. [Cyclone Hazard Proneness of Districts of India](#).

[15] K. J. E. Walsh et al. 2015. [Tropical Cyclones and Climate Change](#). Wiley Online Library.

fresh cut slopes and failures from earthquake events.

C. Outlooks on Adaptation

54. Although the general phenomenon of global climate change is widely recognized, whose impacts are being experienced now, the prediction and visualization of the impacts of climate change at local geographical scales are somewhat hard to pin down. The magnitude of risks from climate change impacts involves a great deal of uncertainty. However, some of the impacts are very highly likely to accelerate road asset deteriorations and damages. This conveys that identification of risks and adaptive responses be given due considerations during the design phase of any investment project.

55. Climate adaptation refers to the actions taken to manage impacts of climate change by reducing vulnerability and exposure to its harmful effects and exploiting any potential benefits. Climate-resilience measures are meant to help reduce, but not fully eliminate the risk of climate change impacts. This is because climate change is a gradual ongoing process and many of its future impacts are not fully discernible at the current moment. It is not easy to make decisions nor is it possible or necessary to do every visualized adaptation measure at once as adaptation and mitigation responses, if necessary, can also be achieved iteratively in later stages based on experience and emerging new information.

56. The process of adaptation is not new as road assets sensitive to climate factors are designed to withstand some variation of climate and associated risks. As to how and when climate change will modify or alter the risk levels, or what should be the acceptable level of risk applicable to the service life of a structure, are challenging questions. Foremost road infrastructure assets vulnerable to climate change that require attention for adaptation measures are those driven by precipitation and temperature changes: (i) bridges and culverts, (ii) roadside drainages, (iii) hillside slopes and embankments, and (iv) pavements.

57. The risks and impacts of climate change for bridges are highly location-specific and the measures to achieve a robust design are complex and vary widely. Each bridge location usually demands some special evaluations such as flood severity, flood water levels, flow velocities, scour potential, sediment transport, slope stability, and modeling of flooding and backwater effects. From a climate change point of view, any cross-drainage hydraulic structure such as bridges and culverts must at minimum pass the anticipated floods without endangering structural integrity and/or loss of service.

58. The longer the lifespan of the infrastructure, the larger the impact of climate change. As such, infrastructural elements that have long service lives such as bridges deserve additional attention during the initial design phase of the project as there may be no or very less opportunities for intervention in the future. Some general adaptation strategies for existing bridges as well as new bridges are summarized in Table 4.[16]

[16] USAID. 2015. Incorporating Climate Change Adaptation in Infrastructure Planning and Design, A Guide for USAID Project Managers – Bridges.

Table 4: Adaptation Strategies for Long-Term Assets

Strategic Approach		Adaptation Strategy	
		Existing Infrastructure	**New Infrastructure**
1.	Accommodate and maintain	• Extend, strengthen, repair, or rehabilitate over time. • Adjust operation and maintenance.	• Design and build to allow for future upgrades, extensions, or regular repairs.
2.	Harden and protect	• Rehabilitate and reinforce. • Add supportive or protective features. • Incorporate redundancy.	• Use more resilient materials, improved construction methods or design standards. • Design for greater capacity or service.
3.	Relocate	• Relocate sensitive facilities or resources from direct risk.	• Site in area with no or lower risk from climate change.
4.	Accept to abandon	• Keep as it is, accepting diminished level of service or performance.	• Construct based on current climate, accepting possibly diminished level of service or performance.

Source: USAID. 2015. Incorporating Climate Change Adaptation in Infrastructure Planning and Design, A Guide for USAID Project Managers – Bridges.

59. Short-term adaptation measures can be applied to assets that normally have short design lives such as drains that line the road and minor cross-drains that fall along the road. For such assets, future climate change impacts and adaptation can be tackled in due course, depending on damages/deterioration/weakening/erosion assessments. This provides the advantage of avoiding the risk of committing to expensive investment at the beginning of the project cycle. When incorporating the concept of short-term measures, an effort must be made to promote adaptation by recognizing the fact that even short-lived assets are bound to face some extreme weather events during their short life cycle. For instance, hydraulic capacity should be increased in areas where the potential for flood damage is greatest. Also, maladaptation must be avoided, such as replacing a structure that has failed due to extreme weather with another of the same specification or standard. While this may provide some relief, it may miss an excellent opportunity to reduce further risk when it is known that weather hazard is increasing in severity or likelihood.

60. While the right amount of moisture in embankments and pavements is needed to achieve compaction, so many of the causes of failed pavements/embankments are due to flowing water and excessive soil moisture. Water influences the behavior and the structural performance of embankments and pavements through separation of grains and destructuring of pavement layers, thus reducing its bearing capacity and resilient modulus. Over time, excess moisture in the structure affects the pavement life cycle by reducing its resilience, thereby becoming susceptible to distresses such as cracks, potholes, or shear rupture. The characteristics of embankment soils, subgrade materials for base courses, and bitumen binders determine structural strength, impact of climate, and durability aspects.

61. In waterlogged areas, the subgrade of pavements is subjected to saturation by water and impacts the load carrying capacity of the subgrade and the strength of pavement layers laid over the subgrade. In addition to waterlogging, roads are also subjected to seasonal flooding. In such cases, it is recommended that the embankment should be raised so that the bottom of the subgrade is above the highest recorded flood level in the areas. While flexible pavement is the generally preferred choice in road construction because of its low initial cost, rigid pavement can be prudently considered as a far better alternative to flexible pavement in marshy and waterlogged areas. Rigid pavement spreads load over a considerable area of subgrade and loss of stiffness

of subgrade due to water has little influence on the structural capacity of a rigid pavement.

62. Stability of natural as well as engineered slopes (such as embankments and cuttings associated with road improvement works) cannot be analyzed effectively without considering the local geologies that contribute to the materials comprising these slopes. Also, it is recognized that beside seismic activities, the severity of the landslide increases with intensity and duration of rainfall. Very often, a single measure may achieve the desired results but sometimes it may be necessary to use a combination of measures to prevent slope failure. Examples include (i) earthworks involving removal of unstable materials from the upper part of the unstable slope; (ii) reducing pore-water pressures in the slope by surface and subsurface drainage; (iii) gulley protection works such as check structures against debris flow; (iv) anchor works that support unstable slopes by rock bolts, soil nails, and ground anchors; (v) supporting the slope by wall and retaining structures; and (vi) bioengineering works that protect from weathering and erosion of slope surfaces by application of vegetative and small-scale engineering works.

63. The morphology, i.e., changes in river forms in plan and cross-sections resulting from processes of erosion and sedimentation of a river, is a strong determinant of flow, and can influence intensification or mitigation of flood waves and torrents. At the same time, when rivers flow in an alluvial plain, they often become meandered or braided, and at times of flood, this morphology leads to excessive bank cutting that can destroy agricultural land, human settlements, and road transport assets. River training and protection works are important measures in the prevention and mitigation of flash floods and general flood control, as well as ensuring safe passage of flood waters under a bridge.

64. Not all adverse consequences of climate change on road infrastructures can be avoided through adaptation, but the MPWD can significantly reduce the extent of damage through proactive actions to avoid, prepare for, and respond to climate change. The structural integrity, performance, and service life of most road assets can be tackled through improved maintenance practices supported by flexible budget—a budget that adjusts according to changes in volumes or activities as opposed to a static budget where fixed amounts are earmarked on an annual-use basis. Here, emphasis is placed on two aspects of road maintenance management:

(i) Preventive maintenance management, where visible deteriorations of the road assets are monitored regularly and remedied immediately before they have a serious impact on the integrity of the road system.

(ii) Adaptive maintenance, which responds to incremental adaptation actions (proactive) and implemented with improvements over short timescales based on gradually increasingly reliable knowledge of climate change impacts.

65. The overall objective of the CECIGM project is to achieve long-term serviceability and economic benefits from an improved road transport system in Maharashtra. As with any investment projects, the most crucial adaptation measure in terms of resilience to both climatic as well as non-climatic events lies in the irrefutable fact that all construction works are well executed, such that deterioration does not result from inadequacies in construction quality and/or deficiencies in the structural properties and/or quality of materials. This crucial oversight and control rests with the MPWD and other stakeholders, and comprises setting and enforcing adequate engineering quality and performance standards during the construction phase.

IV. ADAPTATION AND MITIGATION MEASURES FOR CECIGM

66. In terms of identifying climate change measures, the most effective strategy is to examine current weak spots or deficiencies in relation to observed destructive impacts on operation and maintenance of current assets caused by past extreme weather events. In this regard, the Indian Road Standards IRC-SP:19, which is a manual for survey and investigation, guides the processes for collection of physical information on the existing situation and condition of infrastructure that include (i) terrain characteristics such as hillside slope erosion and landslides, (ii) nature and extent of inundation/damage by floods and high flood levels, (iii) existing pavement layer composition and thicknesses, (iv) embankment soil types, (v) road subgrade and consistency classification, (vi) firmness of protective structures, (vii) drainage types, (viii) conditions and hydraulic adequacies, and (ix) horizontal and vertical geometries.

67. Road surveys have been carried out in all CECIGM subproject roads through visual inspections, dimensional measurements, and investigative tests of materials and their strengths, with the resulting inventories capturing the state of condition and data required for improvement of various climate sensitive assets in the design process.[17]

68. Hydrological assessments have also been carried out for all catchments in the project corridors of CECIGM roads for bridges and culverts. Actual flood records for many of the catchments are said to be not available in dependable sufficiency to enable design engineers to infer worst flood conditions. However, provisions in the design of bridges and culverts have taken recourse to theoretical computations based on several regional empirical methods and iso-pluvial maps for maximum probable precipitation (PMP), and heaviest rainfall intensities in Maharashtra from IMD publications have been adopted in the absence of rainfall data. In addition, topographical surveys of riverbeds supported the bridge design process in the determination of design flood and other parameters such as flow velocity, high flood level (HFL), scour depth, etc.

A. Climate Change Adaptation Features of CECIGM

69. CECIGM infrastructure assets vulnerable to climate change that have been considered for improvements in terms of adaptation/mitigation measures are (i) bridges and culverts, (ii) road embankment geometry, (iii) soil and subgrades, (iv) hillside slopes, and (v) pavements. The cost data for each of the EPCs as estimated by the MPWD are provided in Appendix I of this report.

70. Tables 5 and 6 show proposed interventions in terms of improvement of bridges and culverts along the project roads. The interventions are segregated into activities described as (i) *reconstruction*, where an existing structure is totally dismantled and a new one reconstructed in the same place but with improved structural standards and configurations and meeting updated hydrological assessments; (ii) *conversion,* i.e., upgrade/rebuild an existing minor structure as a major structure with improvements in terms of strength and hydraulics; (iii) *repair/retain*, where an existing structure is repaired/maintained without any major alterations; (iv) *widen*, where an existing structure is widened to accommodate multiple laning; (v) *abandon*, an existing structure is considered as redundant and no longer an asset in the improved highways inventory; and (vi) *new*, where a new structure is built where previously there was none to alleviate flooding problems in underprovided areas.

[17] Engineering Surveys and Investigations, Detailed Project Report, CECIGM.

Table 5: Improvement of Bridges

EPC No.	Major Bridge (span >30 m), Nos.						Minor Bridges (> 6m, < 30m), Nos.						Total Numbers (Minus abandon)
	Reconstruct	Convert – Minor bridge upgraded to major bridge	Repair/Retain	Widen	Abandon	New	Reconstruct	Culvert Upgraded to minor bridge	Repair/Retain	Widen	Abandon	New	
EPC 10			4						2				6
EPC 11		1					1	4					6
EPC 12			4				2	0		2			8
EPC 13							2	3	1	1			7
EPC 14							3	0	5	3			11
EPC 15													0
EPC 16	2											1	3
EPC 17			1						3	1			5
EPC 18		1					2	1	2			2	8
EPC 19							2	2		2			6
EPC 20							6	2					8
EPC 21									2				2
EPC 22							1	4	3				8
EPC 23			1					1	1	6			9
EPC 24							1		2	6			9
EPC 25			2				4	1	2				9
EPC 26							2						2
Total Nos	4	2	11	0	0	0	26	18	23	20	0	3	107
Est. Cost	**₹535.079 million**						**₹741.017 million**						

EPC = engineering, procurement, and construction.

Table 6: Improvement of Culverts

EPC No.	Reconstruct	Pipes/Causeways Upgraded to Box/Slab Culverts	Repair/ Retain	Widen	Abandon	New	Total Numbers (Minus Abandon)
EPC 10	47		3	1		3	54
EPC 11	21		1			0	22
EPC 12	109	10	19		3	36	174
EPC 13	54	5					59
EPC 14	47	9	5	1		7	69
EPC 15	6	3				14	23
EPC 16	46	11				3	60
EPC 17	17	2	7	1		16	43
EPC 18	19	2	3	9		30	63
EPC 19	38	4		1		25	68
EPC 20	16	3				39	58
EPC 21			31				31
EPC 22	54	9				11	74
EPC 23	31	4	2	3	9	35	75
EPC 24	49	4	2	5	3	34	94
EPC 25	68	1	1			0	70
EPC 26	28	7				8	43
Total Nos	643	70	74	21	15	261	1128
Total Cost	**₹1,068.015 million**						

EPC = engineering, procurement, and construction.

71. Table 7 shows the costs of interventions for CECIGM roads and those activities include

the (i) removal of expansive soil (black Deccan soil) to a depth of 500 mm and to be replaced with good quality soil or with soil stabilized with cement and fly-ash; (ii) improvement of embankment height, including improvement of subgrade materials and thickness to maintain bottom of subgrade at a minimum of 0.6 m above HFL; (iii) laying of longitudinal drains along the road; (iii) hill slope and embankment slope stabilization works; (iv) rigid pavement in marshy waterlogged areas; and (v) realignment/new sections of roads that avoid/mitigate risks of urban flooding in congested settlements.

Table 7: Improvement of Embankments, Drainage, Slope Stabilization, Rigid Pavement in Waterlogged Areas, and Realignment

EPC No.	Improvement in Embankment Height in Marshy/ Flood-prone Areas/Subgrade Improvement	Roadside Drains (Urban and Rural)	Roadside Hill Slope Stabilization Works[a]	Rigid Pavement in Waterlogged/ Marshy Areas	New Road Due to Relocation/ Realignment of Road
	Estimated Cost of Works, ₹ million				
EPC 10		31.490	85.380		
EPC 11	149.81	24.230	39.340	13.749	
EPC 12		145.088	261.853	22.915	
EPC 13	73.00	29.810	1.500		
EPC 14	52.66	103.855	8.900		
EPC 15	93.56	19.173	6.25	13.444	
EPC 16		17.836	108.022	73.329	
EPC 17	78.71	109.527	146.739	175.685	61.102
EPC 18	319.39	67.31	138.4	196.156	129.456
EPC 19	542.37	29.47	25.23	146.353	
EPC 20	516.94	72.07	284.32	116.410	
EPC 21	29.84	20.87	5.79	6.111	
EPC 22	193.11	4.606	82.312	39.628	
EPC 23		133.395	156.945	200.311	
EPC 24		136.752	217.000	100.553	
EPC 25	125.24	65.468	24.840		
EPC 26	41.31	7.890	42.210		
Estimated Total Cost (million)	**2,215.94**	**1,018.84**	**1,635.06**	**1,104.64**	**190.56**

EPC = engineering, procurement, and construction.
[a] Works consist of retaining walls, gabion, toe walls, anchors works, and gulley protection works.
Source: Asian Development Bank.

B. Summary of Costs of Climate Change Measures in CECIGM

72. Under climate change considerations, the total cost of an investment project increases by some amount due to additional expenses with respect to a baseline to produce an improved output that results in adaptation and/or mitigation of climate change impacts. A baseline is a business-as-usual scenario referring to the cost of project that is implemented without climate change considerations. The additional expenses are the incremental cost or simply the difference between the full cost of an activity or output prompted by climate change needs and the baseline cost of an activity or output that does not result in adaptation and/or mitigation needs of climate change.

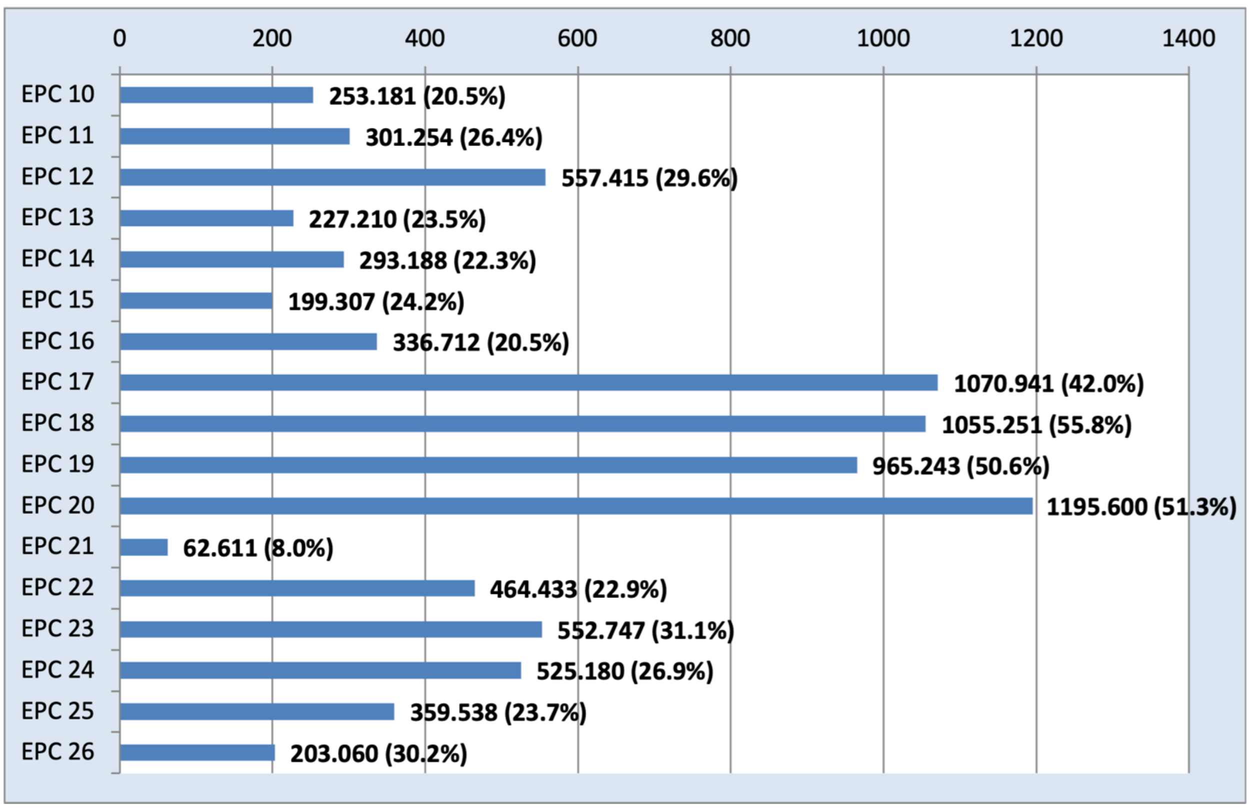
73. In the following tables and figures, the full cost of some of the activities have been justified

as incremental cost without any quantitative differentiation showing what would be the baseline cost or the incremental cost per activity. This assumption of full cost as climate incremental cost was agreed during the discussions with the MPWD because of the following considerations regarding baseline scenarios and costs: (i) the understanding/structuring of what is an acceptable baseline scenario for estimating their costs in the absence of a proper or accepted or consistent methodology(s) or a policy framework and/or lack of data, and (ii) many of the structures have outlived their useful service lives with no residual value and are sunk costs.

74. Table 8 presents a summary of the total project's climate change adaptation costs segregated by work items where climate adaptation features are incorporated in the detailed design of the project roads. The total cost of adaptation/mitigation measures is estimated to be about ₹8,622.87 million, which stands at about 32.6% of the total civil works costs (excluding taxes and miscellaneous expenses) of ₹26,419.3 million.

75. Figure 13 illustrates the estimated climate cost in million ₹ for each of the EPCs. The climate cost expressed as percentage of total civil works cost of each EPC is given in brackets.

Figure 13: Summary of Total Estimated Climate Cost and Proportion in % of Total Estimated Civil Works Cost

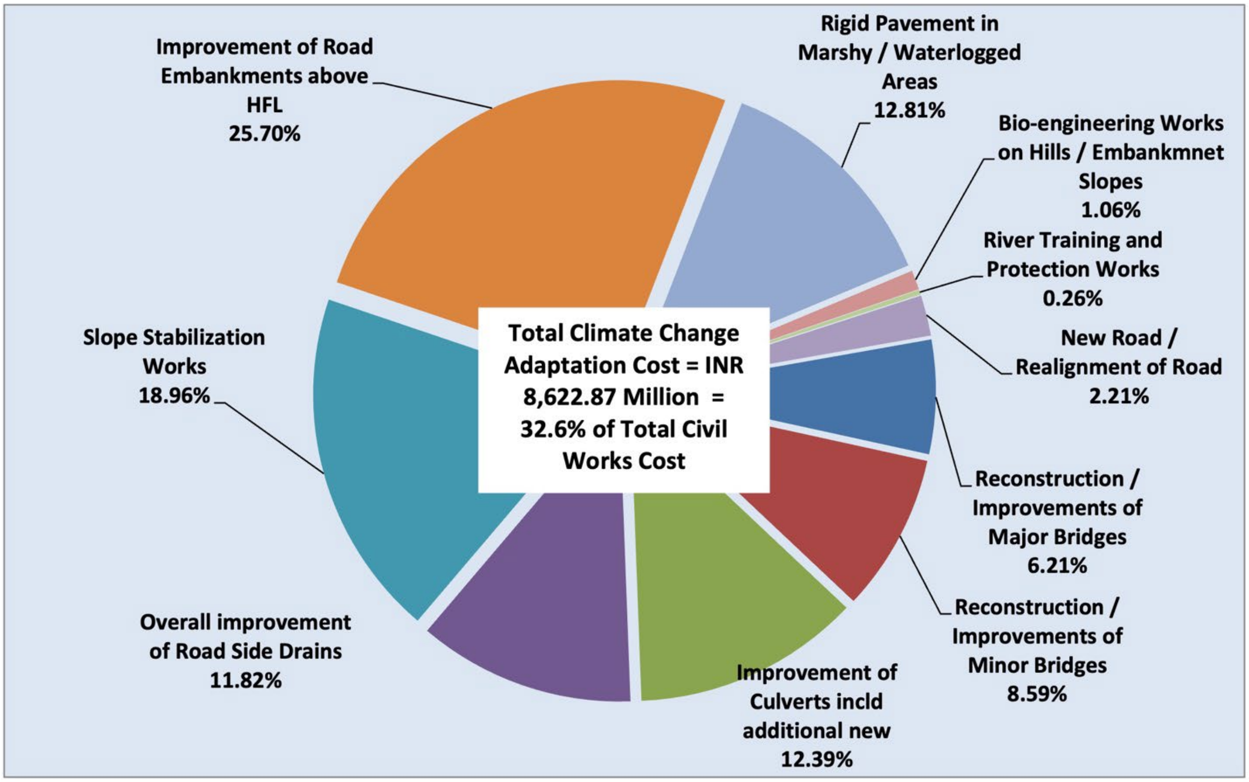


EPC = engineering, procurement, and construction.
Source: Asian Development Bank.

76. Figure 14 shows the breakup of costs for work activities of the total CECIGM project where climate change measures have been incorporated in their detailed designs. The percentages given in the figure represent the proportion of those activities where climate change measures

have been considered against the estimated total climate cost of ₹8,622.87 million.

Figure 14: Proportions of Climate Change Adaptation Costs Expended According to Work Activities



HFL = highest flood level, INR = Indian rupee.
Source: Asian Development Bank.

Table 8: Estimates of Climate Change Adaptation Costs for CECIGM

CECIGM			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
			EPC 10	EPC 11	EPC 12	EPC 13	EPC 14	EPC 15	EPC 16	EPC 17	EPC 18	EPC 19	EPC 20	EPC 21	EPC 22	EPC 23	EPC 24	EPC 25	EPC 26	
#	**Items**	**Works**	Costs in INR Million																	INR Million
A	Bridges	Reconstruction/ Improvements of Major Bridges	0	18.039	0	0	0	0	25.710	446.52	44.81	0	0	0	0	0	0	0.000	0	535.08
		Reconstruction/ Improvements of Minor Bridges	0	33.480	18.936	52.000	47.630	0	41.040	11.78	107.15	106.08	148.42	0	54.205	17.635	18.801	44.210	39.650	741.02
B	River Training and Protection	River Training and Protection Works	0	0	0	0	0	0	0	0	0	0	0	0	22.710	0	0	0	0	22.71
C	Culverts	Improvement of Culverts including additional new	45.301	22.61	108.623	70.900	80.143	66.88	70.775	40.879	52.55	115.74	57.44	0	67.863	44.461	52.074	99.780	72.000	1,068.02
D	Drainages	Overall Improvement of Roadside Drains	31.490	24.230	145.088	29.810	103.855	19.173	17.836	109.527	67.31	29.47	72.07	20.87	4.606	133.395	136.752	65.468	7.890	1,018.84
E	Slope Stabilization	Slope Stabilization Works	85.380	39.340	261.853	1.500	8.900	6.25	108.022	146.739	138.4	25.23	284.32	5.79	82.312	156.945	217.000	24.840	42.210	1,635.06
F	Bioengineered Slope	Bioengineering Works on Hills/Embankment Slopes	91.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91.01
G	Road Embankments	Improvement of Road Embankments above HFL	0.000	149.810	0	73.000	52.660	93.56	0	78.710	319.39	542.37	516.94	29.84	193.110	0.000	0	125.240	41.310	2,215.94
H	Pavement	Rigid Pavement in Marshy/Waterlogged Areas	0	13.749	22.915	0	0	13.444	73.329	175.685	196.156	146.353	116.410	6.111	39.628	200.311	100.553	0.0	0.0	1,104.64
I	Relocation/ Realignment	New Road/ Realignment	0	0	0	0	0	0	0	61.102	129.456	0	0	0	0	0	0	0		190.56
Total Above, INR Million			253.181	301.254	557.415	227.210	293.188	199.307	336.712	1,070.941	1,055.251	965.243	1,195.600	62.611	464.433	552.747	525.180	359.538	203.060	8,622.87
Total Civil Works Cost (minus taxes and miscellaneous), INR Million			1,233.30	1,142.00	1,882.30	966.10	1,317.50	824.80	1,639.60	2,551.67	1,889.54	1,908.79	2,331.42	784.45	2,031.83	1,775.60	1,954.90	1,513.90	671.60	26,419.30
Climate Change Adaptation Cost as % of Total Civil Works Cost			20.5%	26.4%	29.6%	23.5%	22.3%	24.2%	20.5%	42.0%	55.8%	50.6%	51.3%	8.0%	22.9%	31.1%	26.9%	23.7%	30.2%	32.6%

CECIGM = Connecting Economic Clusters for Inclusive Growth in Maharashtra, EPC = engineering, procurement, and construction, HFL = highest flood level, INR = Indian rupee.
Source: Compiled from data provided by the Maharashtra Public Works Department. Data sheets for each of the EPCs may be obtained upon request.

C. Climate Change Mitigation Measures Considered in the Project

77. With the rising growth of urbanization and other anthropogenic activities, there is a huge demand to improve the transportation infrastructure for economic growth of the nation. With this goal, many infrastructure projects such as state and national highways are being developed across the country, improving last mile connectivity. Although the pace of development has increased, there is a constant struggle for civil engineers to implement environmentally friendly methods of construction that will have the least impact on the environment including reduced GHG emissions. Soil stabilization is one such approach that utilizes native soil for treating so that the replacement of existing soil with borrowed material is avoided. This results in less carbon footprint due to reduced construction operation less new borrow areas that are dug.

78. Unsuitable and expansive soils are found in many parts of India and contribute to early pavement failures, which in turn cause higher repair and rehabilitation costs. As subgrade is the foundation of a pavement structure over which the vehicular loads are applied, a stable and durable embankment/subgrade is required for long-lasting pavement performance. Highly plastic clays are generally found unsuitable for pavement construction due to the non-uniform swelling of soil, causing premature pavement cracking. Based on the standard specifications as per the Ministry of Road Transport and Highways, the engineering properties evaluated for the identification of expansive soils are Liquid Limit (LL), Plasticity Index (PI), Free Swelling Index (FSI), and Dry Density. Conventionally, to tackle the problem of soft soils is to remove the unsuitable soil up to a depth such that the overburden pressure counteracts the swelling potential of the subgrade and replaces this lost material with fresh “inert” soil. However, in this process, the existing dug-up material must be dumped and stored at a facility, increasing the environmental impact of additional land requirement and disturbing the existing flora and fauna around. This process also involves loss in terms of the energy, cost, and human resources involved. Moreover, in stretches with unsuitable soils, it is generally difficult to obtain borrow area sites with good quality soil within reasonable construction lead. Obtaining this new material will not only cause environmental impact but also have financial implications on the project due to the scarcity of the resource. Hence, rather than obtaining additional material, in-situ ground improvement using cement/lime treatment seems a more sustainable solution.

79. Stabilization using cement/lime is an established practice to improve the characteristics of unsuitable soils. Stabilization process is used to improve the properties of expansive soils by reducing the swelling potential and improving the existing soil strength (CBR). Generally, 2%–6% of cement/lime by weight of dry soil is required for the stabilization based on the type and property of the soil being treated. This operation is carried out in-situ by addition of stabilizer and reworking the ground along with curing of the finished compacted layer, lowering the need for embankment materials including transport and thereby lowering GHG emissions during construction.

80. In-situ soil stabilization will be employed in four EPC packages (EPC 10, 11, 13, and 26). This method is more sustainable than traditional methods as it reduces the need for transporting raw materials for embankment construction from borrow areas. As most subproject roads are within 300-km distance of thermal power plants, fly-ash may be suitably used in soil stabilization for these roads, which further increases the benefit of reducing the need for raw materials. The entire cost of soil stabilization was taken for these four packages as mitigation measure.

81. Considering that CECIGM roads are to be rigid paved, the scarified pavement asphalt from the existing roads after properly crushing and screening would be high-quality well-graded aggregates. At the most, 80% by weight of the reclaimed asphalt can be recycled to be used as granular or stabilized base courses (GSB) or as embankment fill materials. The 20% would be a

mix of organic materials, hardened asphalt cement (bitumen), dirt and dust, etc. The MPWD commits to maximizing the recycling or reclaiming of old pavement materials, which are of high-quality fit for the GSB. It is estimated that least 30% of the cost of the crushed stones used in the GSB can be offset by recycled pavement asphalt. Note that the GSB is composed of a mix of sand and gravel, and crushed stone, where slightly >50% of GSB is crushed stone from quarries. This would roughly mean that mitigation of 15% (30% of 50%) of the total cost of GSB as recycling will reduce the need for raw materials for GSB at a conservative estimate. This is considering that recycled asphalt may also be used for access roads aside from embankment. These two activities fall under “demand reduction” in cross-sectoral activities category in the list of eligible activities specified in the latest joint Multilateral Development Bank Common Principles for Climate Mitigation Finance Tracking.

82. Lastly, afforestation forms a small amount of the civil works cost. A 70% survival rate for avenue plantation by contractors has been set for the project. A total of 7,679 trees will be felled for the project. Considering this and the additional plantation ratio of 1:3, it is estimated that the project will result in 16,125 mature trees. These are likely to sequester atmospheric carbon dioxide at an average of 22 kg/year of CO_2 per mature tree per year.[19] Therefore, it is estimated that this activity will contribute toward the reduction of CO_2 by 354 tons/year.

83. These three activities bring the mitigation costs under the project to ₹445 million. Mitigation costs in the project are summarized in Table 9.

[19] Arbor Day Foundation. *Tree Facts.*

Table 9: **Summary of Mitigation Costs Considered in CECIGM**

EPC Package	Cost of Soil Stabilization	Recycled Asphalt	Tree Plantation	Total
EPC 10	22.79	14.107	2.979	39.88
EPC 11	14.81	12.786	0.292	27.89
EPC 12		23.936	7.778	31.71
EPC 13	31.62	11.525	2.260	45.40
EPC 14		12.310	2.337	14.65
EPC 15		7.114	0.619	7.73
EPC 16		16.550	1.621	18.17
EPC 17		9.104	2.623	11.73
EPC 18		18.960	5.951	24.91
EPC 19		15.550	5.057	20.61
EPC 20		17.369	4.186	21.55
EPC 21		0.303	3.925	4.23
EPC 22		23.841	5.513	29.35
EPC 23		21.734	5.777	27.51
EPC 24		23.172	8.318	31.49
EPC 25		36.042	3.528	39.57
EPC 26	41.32	4.888	2.881	49.09
Sum above	110.53	269.29	65.64	**445.47**

CECIGM = Connecting Economic Clusters for Inclusive Growth in Maharashtra, EPC = engineering, procurement, and construction.
Source: Asian Development Bank.